Vol. 65, No. 6 November, 1958

Psychological Review

THEODORE M. NEWCOMB, Editor
University of Michigan

CONTENTS

Herbert Sidney Langfeld: 1879–1958.....CARROLL C. PRATT 321

Psychological Structure and Psychological Activity.....HELEN PEAK 325

Basic Issues in Perceptual Theory.....W. M. O'NEIL 348

A Concept-Formation Approach to Attitude Acquisition.....RAMON J. RHINE 362

Symptoms and Symptom Substitution.....AUBREY J. YATES 371

Transfer of Training and Its Relation to Perceptual Learning and Recognition.....JAMES M. VANDERPLAS 375

The Perceptron: A Probabilistic Model for Information Storage and Organization in the Brain.....F. ROSENBLATT 386

This is the last issue of Volume 65.
Title page and index for the volume appear herein.

PUBLISHED BIMONTHLY BY THE
AMERICAN PSYCHOLOGICAL ASSOCIATION, INC.

Consulting Editors

Solomon E. Asch	Robert B. MacLeod
Robert R. Blake	David C. McClelland
Stuart W. Cook	George A. Miller
Clyde H. Coombs	Frederick Mosteller
William K. Estes	Gardner Murphy
Leon Festinger	Oscar Oeser
W. R. Garner	Carl Pfaffmann
James J. Gibson	Carroll C. Pratt
D. O. Hebb	John P. Seward
Harry Helson	David Shakow
E. R. Hilgard	Richard L. Solomon
Carl I. Hovland	Eliot Stellar
E. Lowell Kelly	S. S. Stevens
David Krech	Eric Trist
Robert W. Leeper	Edward L. Walker
Kenneth MacCorquodale	Robert W. White

Arthur C. Hoffman, Managing Editor

Helen Orr, Promotion Manager

Herbert Nell, Editorial Assistant

The *Psychological Review* is devoted to theoretical articles of significance to any area of psychology. Except for occasional articles solicited by the Editor, manuscripts exceeding twelve printed pages (about 7,500 words) are not accepted. Ordinarily manuscripts which consist primarily of original reports of research should be submitted to other journals.

Because of the large number of manuscripts submitted, there is an inevitable publication lag of several months. Authors may avoid this delay if they are prepared to pay the costs of publishing their own articles; the appearance of articles by other contributors is not thereby delayed.

Manuscripts should be submitted to the Editor-elect, Richard L. Solomon, Emerson Hall, Harvard University, Cambridge 38, Massachusetts.

PUBLISHED BIMONTHLY BY THE

AMERICAN PSYCHOLOGICAL ASSOCIATION, INC.

PRINCE AND LEMON STREETS, LANCASTER, PA.

1333 SIXTEENTH ST. N. W., WASHINGTON 6, D. C.

$8.00 volume $1.50 issue

Entered as second-class matter July 13, 1897, at the post office at Lancaster, Pa., under Act of Congress of March 3, 1879

Acceptance for mailing at the special rate of postage provided for in paragraph (d-2), Section 34.40, P. L. & R. of 1948, authorized Jan. 8, 1948

Send all communications, including address changes, to 1333 Sixteenth St. N.W., Washington 6, D. C. Address changes must arrive by the 10th of the month to take effect the following month. Undelivered copies resulting from address changes will not be replaced; subscribers should notify the post office that they will guarantee second-class forwarding postage. Other claims for undelivered copies must be made within four months of publication.

© 1958 by the American Psychological Association, Inc.

VOL. 65, NO. 6 NOVEMBER, 1958

THE PSYCHOLOGICAL REVIEW

HERBERT SIDNEY LANGFELD

1879–1958

In 1904 Herbert Sidney Langfeld resigned his position as Secretary to the Naval Attaché of the American Embassy in Berlin, for he had decided against a career in the foreign service in favor of graduate study in psychology at the University of Berlin. This decision brought a real loss to American foreign service, for in the very best sense Langfeld was a diplomat to the manner born; but at the same time it was an important gain for American education in general and psychology in particular. Langfeld was the last American to study under the first generation of German psychologists, and revealed during his long career in this country, both as teacher and administrator, a serene wisdom and detachment together with a breadth of outlook which may have resulted in part from his experiences in the German universities. The psychologists with whom he studied in Germany were also philosophers with imposing ideas and a sweep of imagination which often made up for their lack of knowledge regarding the experimental techniques and statistical analyses in which our students today are so carefully trained.

Dr. Langfeld received his early education at the Central High School of his native Philadelphia and at Haverford College. After he enrolled in the University of Berlin he did most of his work under Carl Stumpf and received his Ph.D. under him in 1909. He published several articles in the *Zeitschrift für Psychologie* in the field of visual phenomena, rather than in Stumpf's favorite field of audition. At the same time he showed a profound interest in art which remained with him throughout his life, and spent many hours in museums and in the classrooms of art historians and aestheticians. On returning to this country he accepted a position as instructor in psychology in Harvard College. When he left Emerson Hall fifteen years later he had served Harvard as associate professor and director of the laboratory for a number of years, had written articles on a variety of topics both within and outside the field of experimental psychology, and in 1920 had published his most distinguished and best-known book, *The Aesthetic Attitude*. He had also written, in collaboration with Floyd Allport, a laboratory manual which was widely used in various universities for a number of years.

Langfeld was a good lecturer, skilled in clear exposition and in the use of language "understanded of the people." He was not dramatic, nor did he ever lose his natural dignity by trying to be popular or obvious. The duller students were not impressed, but he had the teacher's reward of knowing that those who took the pains to follow and grasp his ideas retaine an enduring and fa-

vorable impression. Tucked away in his desk Mrs. Langfeld recently found a petition signed by a large number of Harvard graduate students begging him to offer a special course in systems of psychology because of their conviction that he could give them a scope and depth of insight which they felt they badly needed. In a recent volume, *College in a Yard,* one of the many distinguished contributors who recalled their memories of famous teachers at Harvard wrote that "In psychology and aesthetics there was Herbert Sidney Langfeld, whose occasional ironies were as nice, as elegant and impeccable as his habit."

In 1924, on the completion of Eno Hall, Langfeld accepted a call to become Professor of Psychology at Princeton and to succeed Howard Crosby Warren as Director of the Psychological Laboratory. Warren had managed to separate psychology from philosophy only three years before, with the result that he and Langfeld were burdened with the heavy responsibility of building up a department faced with indifference, if not opposition, from the philosophers and the administration towards what William James once called "that nasty little subject." In 1932 Langfeld became Chairman of the Department and in 1937 was awarded the Stuart Professorship. During the years until his retirement in 1947 the department more than doubled in size of staff and in the scope of its activities. Langfeld became deeply devoted both to the town and gown of Princeton, and resented any criticism of the institution or the department almost as though it were a personal affront. On rare occasions he allowed himself the privilege of speaking with disfavor about minor matters relating to Princeton, but it was not good form for anyone else to do so in his presence. He was admired by graduate students and members of his staff, for they accepted his pride in their work as a challenge to their best efforts. They always referred to him affectionately as "Langie," but not when he was within earshot. When Wever and Bray made themselves famous by their studies in audition, he experienced the satisfaction and delight of one who was somehow sure that only in his laboratory could such important ideas be born.

Throughout his writings there appear numerous variations on the theme of a motor theory of consciousness, or, as he preferred to call it, a response psychology. This view has always been closely associated with his name, although in one of his articles he disclaimed any credit for formulating the theory and showed in impressive detail its origins and development from Greek philosophy down to the immediate predecessors of behaviorism. Undergraduates both at Harvard and Princeton were always warned by their tutors and preceptors that they should know the motor theory forward and backward, for no matter how varied the wording of an examination question, there could be only one correct answer. Langfeld was never able to believe, as did some of his German professors, that consciousness can be isolated for phenomenological study in its own right. It is too closely linked to efferent as well as to afferent events. The data of sense, as well as those of perception, feeling, cognition, and emotion have their terms interpenetrated and closely bound up with motor processes.

This view of mind, with its emphasis on motor response, led into and was then swamped by the behaviorism of the 1920s. With radical behaviorism, however, Langfeld had no sympathy; and it is gratifying to realize that he lived long enough to see his own view, albeit with new and more elaborate terminology, restored to its proper and appointed place in the psychology of today. He was often amused by the tortuous labor of those who had not

fully recovered from the behavioristic revolt to find "objective" sentences for the description of what at one time would have been called simply direct experience or consciousness. He knew that consciousness by any other name would still be the same thing, and he continued to insist that the data of classical psychology are an inescapable part of the intricate chain of external and internal events that make up the totality of mental life, and that these events are best looked upon and labeled as neutral rather than either subjective or objective. His refusal to become involved in any sort of body-mind controversy was undoubtedly reinforced by his close association with the philosopher-psychologist, Edwin B. Holt, who frequently argued that attempts to tell what is objective and what is subjective are a waste of time for the simple reason that they never get anywhere.

In his writings on aesthetics, and especially in *The Aesthetic Attitude*, Langfeld drew heavily on the doctrine of empathy for an explanation of the very special and affective perceptual qualities of art. Hardly anywhere in English can a more persuasive account be found of the manner in which incipient muscular movement may conceivably be the basis of the judgment that a work of art is exciting, wistful, melancholy, sprightly, or what not. The problem is among the oldest in speculation about art and has given no end of trouble to philosophers, art critics, and psychologists. It seemed absurd to argue that the perceived object of art itself could be melancholy; and there was good evidence to show that those who described a work of art in such manner were not ordinarily in a melancholy state. Here was a problem, for if neither the object nor the subject is melancholy, where does the quality come from? Langfeld seized upon Lipp's doctrine of *Einfühlung* and worked it for all it was worth. Aesthetic qualities must somehow have their origin in the subject, but are immediately and unconsciously projected upon and identified with the object, so that it is the object which *seems* to be melancholy. The notion is an obvious variation on the theme of a motor theory of perception, and was therefore doubly congenial to Langfeld because of its close relation to his more general point of view in psychology.

In recent years, however, the theory of empathy has been severely attacked, and Langfeld was placed in a much more defensive position with respect to many of the arguments to which he was deeply attached. The implications of *Gestalttheorie* for art, especially in some of the devastating paragraphs of Koffka and Köhler, were drawn upon by a number of philosophers and psychologists to reveal the serious limitations of empathy. The doctrine gives too little credit to the genius of the artist. It implies that the subject creates from within himself the glories of the glass of Chartres, the majestic power of the sculpture of Michelangelo, and the wistful melancholy of some of the minuets of Mozart. The artist merely puts together a sort of neutral perceptual design and then waits for the subject to perform the act of artistic creation. Because this act seems too much to hope for, the pendulum has swung in the direction of assigning to the artist the ability to create configurations which themselves possess the *tertiary* qualities of longing, serenity, erotic passion, sadness, gaiety, etc. Sadness may be present in visual and auditory as well as in organic impressions. It is this possibility of multiple location that has caused the confusion in aesthetic theory. A person may feel sad. A piece of music may sound sad. But neither state necessarily depends on the other. It is not empathy which gives to the slow movement of the *Eroica* the sense of poignant grief. It was Beethoven who performed that miracle, and for

those with ears to hear, it is a source of pleasure rather than of grief, although the judgment may be made that the music is profoundly sad. Yet the doctrine of empathy is still widely held, and may in time recover from its wounds. There are few views in philosophy and psychology which are completely down and out. In any case, Langfeld's treatment of *Einfühlung* is masterly and for a long time will remain required reading for every student of aesthetics, for even if a student entertains doubts about empathy he must know how to answer the penetrating arguments which Langfeld has marshaled in its support.

Langfeld's eclectic interests in psychology and his respect for good writing made him an ideal editor. As the years went on, he spent an ever increasing amount of time in going over manuscripts with painstaking care for professional journals and for the publishing house of John Wiley and Sons. In 1931 he was appointed editor of the *Psychological Monographs*, and then for thirteen years served the *Psychological Review* in a similar capacity. He was joint author and editor of a number of texts, the best known of which was the famous *BLW*, a factual foundation for psychology which he, Boring, and Weld prepared for such advanced introductory courses that many graduate students have used it to bone up for their final oral examinations. His services to psychology have been recognized in a variety of ways. He was an honorary member of the Belgian and Swedish Psychological Associations, and in 1930 was elected president of the American Psychological Association. His election to the Pontifical Academy of Sciences in 1949 and the private audience with His Holiness Pope Pius XII gave him, an Episcopalian, deep pleasure and satisfaction, as did also the award of *Docteur de l'Université* which he, Michotte, and Piéron received from the University of Montreal at the time of the 14th International Congress of Psychology.

Throughout his long professional career Langfeld provided a valuable link between psychology in America and psychology in other countries. He was Chairman of the Committee on International Cooperation in Psychology of the National Research Council, and Permanent Secretary of the International Congress of Psychology, and in his many travels abroad he established close personal and professional relations with investigators in other countries. It is safe to say that no American maintained such friendly contacts with so many psychologists in other lands. Whenever his professional friends had a chance to come to this country, they hastened to accept Langfeld's invitation to visit him in Eno Hall and to partake of the hospitality so generously offered by Dr. and Mrs. Langfeld in their Princeton home.

Retirement made little change in the routine of Langfeld's life except for the freedom from classroom instruction and administrative responsibilities. He came regularly to his office in Eno Hall, carried on voluminous correspondence regarding professional matters all over the world, wrote articles and prepared lectures to be delivered before learned societies in this country and abroad, watched with deep interest but without any interference the activities of the department over which he presided for so many years, and continued to extend the hospitality of his home to graduate students, members of the staff, and especially to visitors from abroad. Shortly before his death he spoke informally at one of the regular seminars in Eno Hall. He left an indelible impression both with staff and students of his ability to expound clearly the broad historical background for his sharp comments about contemporary psychology.

CARROLL C. PRATT
Princeton University

Psychological Review
Vol. 65, No. 6, 1958

PSYCHOLOGICAL STRUCTURE AND PSYCHOLOGICAL ACTIVITY [1]

HELEN PEAK

University of Michigan

The science of behavior, like all science, is preoccupied with relations between events. For this reason, it is important to analyze the diverse relational concepts that have been employed in describing psychological structures, in order to discover whether unique characteristics belong to concepts such as similarity, opposition, complements, antecedents, and consequents, or whether they are all reducible to simpler and more fundamental relational properties. Another paper (**28**) has suggested that all kinds of psychological structures can be described in terms of parts or events standing in spatial and temporal relations to each other, the space being conceived in psychological terms; and that every arrangement implies the course that activity will take when the structure is activated at specified points. It will be the task of the present paper to elaborate this analysis in somewhat more detail and to suggest how selected structural patterns influence the course of events in perceiving and acting.

The properties of structure will be described and certain basic principles about the relation of structure and activation will be proposed. These will be discussed as they apply to phenomena such as context effects, assimilation and contrast, the algebraic summation of positive and negative attitudes to produce intermediate attitudes, judgment within "balanced" and "unbalanced" structures as described by Heider (**11**), and the persisting activity of the motivated state.

[1] This article was written in connection with ONR Contract Nonr-1224(10) NR 171-039 with the University of Michigan.

Psychological Structure

If the course of psychological events is to be predicted from information about the activation pattern imposed on a known structure, the meaning of the central concepts involved must be made clear, most particularly the notions of structure and activation.

Stated briefly, activation is a term similar in meaning to stimulation but more general in the sense that the change which *activates* a structure may be either the energy change which takes effect by way of sense organs (a stimulus) or a central event, such as an aroused concept, which in turn produces change in or activation of another structure. Activation is transmitted change.

The term *structure* is used in a very broad sense to refer to a system of relationships between identifiable parts. It is a hypothetical construct[2] to be inferred from events observed under specified conditions and, like all such constructs, once inferred, it becomes the basis for predicting behavior on subsequent occasions when there are reasons to believe that the

[2] The term has a less restricted meaning in this paper than is given it by Meehl and McCorquodale (**22**). The ideal is, of course, to define any construct rigorously both at the conceptual and at the operational level in order that the same structure will be inferred from the various events to which it is assumed to contribute. But the degree of rigor of the definition does not determine whether it is a construct or its hypothetical character.

system of relations has not changed. For example, if it is ascertained that under free association instructions the stimulus word *black* elicits the response *white* 80 percent of the time in some population or in some individual on a series of occasions, then it is inferred that there is a relationship between the stimulus-aroused concept and another part of the structure whose activation produces the observed response. This familiar fact that organisms retain dispositions to react in certain ways must imply that the underlying structural arrangements have a basis in the nervous system. However, it is not our purpose to present a neurological model. Rather the intent is to describe certain patterns of relations which are compatible with important psychological phenomena. The neurological substrate of these phenomena may or may not possess characteristics of the kind to be described.

Now the components of a structure will vary not only with the subject matter of the particular science but also with the theoretical preferences of the scientist. But parts of some kind must be identified, whether they be called stimuli, roles, concepts, regions, R_g, attitudes, cathected objects, or drives—to mention a few miscellaneous constructs that have been regarded as segments of the matrix of events by equally miscellaneous psychologists. Moreover, it should be noted that the components of a structure are not to be regarded as indivisible elements, for some components may be highly structured with relations existing between the parts, as in the complex concept of a friend, while others are relatively simple and homogeneous, as would be the concept of warmth. This means that there may be relations *within* components parts as well as *between* parts of a larger structure.

It has already been noted that the nature of the relations existing between the parts of a structure will be a principal concern of this discussion and that the effort will be made to conceptualize the more complex relations in terms of the concepts of position and distance. Therefore, these basic relational notions must now be defined.

Position

To assign position means, generally speaking, to place an event or a point in relation to one or more other events. In the simplest case, position depends on the process of identifying and distinguishing an event from other events, and to have the same position means simply to be in the same category.

But position may be specified more precisely if events have been ordered on a continuum or arranged in a series which derives its order either from the amount of a property or from the temporal order of activation of the individual parts of the series when one part is activated. In other words, position may be stated in terms of membership in a category (nominal position) or in terms of some amount of a property or position in a series (ordinal position, or a point on an interval or ratio scale).

Distance

The psychological distance from any point A to point B is defined in terms of the number of units or steps in an ordered series of some kind which intervene between A and B which are themselves part of the series.

If, then, two points have only nominal position in separate categories, their distance apart will be indeterminate unless the categories themselves can somehow be ordered.

In other words, the description of a distance must involve finding a method of ordering events before it can be established (*a*) that other points of a series do in fact lie between *A* and *B*, and (*b*) that there is some determinate number of such intervening events that define the distance.

Further, it must be noted that psychological distance has a special property which makes it different in this respect from physical and mathematical distance: it need not be symmetrical. The distance from *A* to *B* is not necessarily the same as from *B* to *A*. For example, the occurrence of an event which is an antecedent will more often elicit the consequent as an associate than presentation of the consequent will elicit the antecedent. It is inferred that the distance is greater from consequent to antecedent than in the other direction.

Although this is not the appropriate place for a discussion of all the operations for determining order and distance among psychological events, a few examples of operations from which psychological distance has been inferred will make it clear that all imply the foregoing definition. Distance between two points may be inferred from judgments of the position of each point on a scale. The subject matches his reaction to the stimulus objects to some scale position and the difference in position represents the number of intervening units. Or distance may be judged directly where the subject is asked to state how far apart two stimuli are. For example, he judges how different John and Jim are in intelligence, and reports it. The units used in the judgments and their distance apart may or may not have been scaled by techniques such as those developed by Thurstone (**36**), Coombs (**8**), Guttman (**35**) and others, but all these methods imply the occurrence and identifiability of intervening steps of some kind. Furthermore, the relative frequency and the latency with which one event follows another have also been considered to reflect distance between events. Indeed, probability of activation of one event by another is often taken as synonymous with distance (**26**).

If it be assumed that each of these measures reflects in some degree a distance between A' and A'' in psychological space, the major operational problem is to find ways of removing the effects on behavior of determinants other than distance A'–A'', for it is only when these irrelevant determinants have been partialled out of each operation that the various operations for inferring this distance can be made comparable.[3]

Direction

Direction involves determining position of some event with respect to two or more other positions.

The course of activation can be said to have direction, but there is a question whether direction is a necessary concept for the description of structure. Suppose that I know three boys, Tom, John, and Jim, whose IQs are 100, 110, and 115. It is possible to say that John's IQ lies in the direction of Jim's from Tom's, and that Jim's and Tom's are in opposite directions from John's, in my psychological structure. But this description in terms of direction adds little to a statement in terms of position and distance. It is when predicting the course of activity within a structure that the concept of direction becomes

[3] See Hilgard and Marquis (12, p. 135) on the low correlation between indicants of habit strength, such as the probability of activation of *A* by *B*, judged similarity of *A* and *B*, generalization of response from *A* to *B*, speed of extinction, latency, etc.

useful, for it is necessary that information about the points of input into a structure be provided, in addition to knowledge of the structure itself, before the direction of events can be determined. It is the relation of subsequent events to the initial point of activation or the input point that gives direction.

ACTIVATION

To say that a structure has been activated means that change from some source has set off change in a structure. Thus the energy change that is a stimulus event, such as the spoken word *good*, initiates a successive wave of change in parts of a complex structure finite distances apart until the process leads finally by a series of activations to the spoken word *bad*. Potentiality for this series of events implicit in the structural arrangement has been actualized by the transmittal of change from one point in the structure to other points.

In some cases activation produces only a temporary disruption of the structure which tends to be reconstituted following activation. Thus a violin string is distorted when a bow is drawn across it but soon returns to its original state. In a somewhat different way, neurone structure is partially destroyed in responding to stimulation but is polarized again after the passage of an impulse. Again, the activation of a series of concepts, percepts, movements, or word responses involves structural change, but here, too, activity subsides and the original state of quiescence returns.[4]

But activation may leave an altered structure, which means that the structure does not invariably return to the preactivation state. This is known to be the case when later activation at the same point, under conditions otherwise the same, produces a different outcome. Restructuring or learning has occurred. The presentation of a complete learning theory is beyond the scope of the present discussion, which addresses itself primarily to the problems of the immediate effects on perceiving and acting of activating a given structure at a given point or points. However, it may be said that any condition which has the effect of activating two structures close together in time increases the probability of a change in the relationship between the structures. Furthermore, the shorter the existing distance between the structures when activated, the more likely it is that their simultaneous activation will reduce the distance still further. The role of affective consequences in learning cannot be considered at this time.

ACTIVATION PRINCIPLES

Structure is of interest only insofar as it determines the course of activity. The next step is, therefore, to analyze certain assumptions that must be made about the relation of activation and structure. Five principles are proposed that appear to be necessary in order to derive theorems about activation patterns that develop within particular structures. The validation of these constructs will depend upon the success with which they generate propositions which are verifiable. At present they derive their justification from the fact that they appear to be compatible with certain phenomena for which there is observational support.

Distance and Activation

It is assumed that the probability of activation of some point *B* when *A*

[4] The disruptive events of activation and the opposed tendency to reconstitute structure suggest entropy principles, activation corresponding to positive entropy and reconstitution of structure to negative entropy (33).

is activated is an inverse monotonic function of the psychological distance between A and B, when other sources of the activation of B are excluded (Principle I).

As already explained, the activation of any point in psychological space may be determined by input from more than one source, and it is only when activation of B from other sources is controlled that this relation can be assumed to exist between distance A–B and the probability of activation of B by A.

As a matter of fact, it must be the exceptional occasion when input to any point in a complex structure comes from only one source, and so it is necessary to make assumptions about the way in which activation from different sources combines to determine the next steps in the activation pattern. There appear to be two basic patterns which demand different combination principles. In the first, a serial arrangement, activation of some structure at the end of the series depends on the occurrence of activation in preceding steps of the series. In the second pattern, structures are arranged so that there is multiple input to the same point from two or more sources.

Serial Arrangement

In a serially arranged structure, the probability of activation of some point C at the end of the series when a point S is activated is the product of the probabilities of activating points intervening between S and C (Principle II).

For example, in Fig. 1 the probability that S_a will activate C equals 0.63 (0.9×0.7). The probability that S_b will activate C equals 0.36 (0.9×0.4).

Multiple Input to the Same Point

The probability that any point will be activated is a function of the combined probabilities of its activation from all currently active structures. Given the probability that A will activate C and that B will activate C, the probability that A and B together will activate C is assumed to be equal to:

$$1 - (P_{cA} \times P_{c\bar{B}})$$

where P_{cA} is the probability that A alone will *not* activate C and $P_{c\bar{B}}$ is the probability that B alone will *not* activate C (Principle III).

For the values given in Fig. 1, the probability that A and B together will activate C is equal to 0.77; that is, the combined probability is greater than the probability produced by either component (A or B) except when the probability of one or both terms is zero or unity.

The logic of the assumption is simply this. The probability that C will occur when both A and B are activated is the sum of those occasions where A activates C but B does not ($P_A \times P_{\bar{B}}$), where B alone activates C but A does not ($P_{\bar{A}} \times P_B$) and where both activate C ($P_A \times P_B$). In other words, the relative frequency is reduced by the frequency of those occasions on which neither A nor B activates C (probability that C not activated $= P_{c\bar{A}} \times P_{cB}$). This is the term subtracted from unity in the equation.

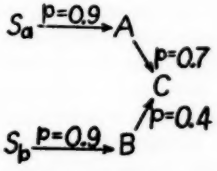


FIG. 1. Serial arrangement of parts: $S_a \rightarrow A$, $A \rightarrow C$; $S_b \rightarrow B$, $B \rightarrow C$. Multiple input to the same point: $A \rightarrow C$ and $B \rightarrow C$.

Examples of situations in which complex multiple input may be assumed to occur are numerous. The many studies which emphasize the effect of preparatory events, such as context, set, instructions, and perceptual response dispositions on reactions to stimuli, belong here. Howes and Osgood (**15**) showed, for example, that both the number of preparatory stimuli similar to a word and the interval by which those preparatory stimuli preceded a stimulus word influenced the nature of the free association response made to the word. The preparatory stimuli may be assumed to have activated the same structure as did the stimulus word, and thereby to have increased the probability of the occurrence of a response depending on activity in that structure. And Asch's well-known demonstration (**1**) of the effects of prior presentation of trait terms, such as *warm* and *cold* on the interpretation of other traits attributed to an individual, may illustrate the same point.

It appears that the influence of central motivational states on perception and action may likewise be conceived in terms of multiple input. Many examples come to mind, such as the familiar studies of Atkinson and McClelland (**2**), in which TAT stories were written under different degrees of hunger motivation, with the consequence that references to eating and/or activities instrumental to getting food increased with increased time of deprivation.

Again, the apparent increase in the breadth of the generalization gradient when drive level is high or with high anxiety may also involve this same principle, if it is assumed that anxiety or high levels of motivation set up diffuse activation and hence multiple input to all points on a gradient. Finally, it should be noted that the process of abstraction should also be examined with this principle in mind. A property common to different situations is more likely to be noticed if an individual experiences a number of different events all of which possess the property. Thus the European who sees ten Americans chewing gum is more likely to abstract a concept of gum-chewing Americans than if he has only one such experience. The multiple input to the gum-chewing property increases its probability of arousal.

Event Units

Bridgman has aptly described the problem of setting boundaries to physical events when he says, "I believe the essence [of the identification of an event] lies in the discrete character of the event. . . . An event is by definition the aggregate of all phenomena bounded by certain discontinuities." He then goes on to point out that this concept can only be an approximate one, because there are no such things in experience as sharp discontinuities. Rather, as measures become more refined "the edges of the supposed discontinuities become blurred" (**5**, pp. 95–96).

This is the problem of discovering cleavages in the matrix of events, the boundaries which result in some events being part of the same whole while others are parts of different wholes. This search for gaps between phenomena is involved in delimiting the boundaries of perceived objects or of concepts, in determining what is included in a trait complex and what is excluded, in bringing it about that events will be "assimilated" or "contrasted."

It is proposed that the discontinuities that establish boundaries in psychological space are of two kinds: (*a*) the distance between events,

decreasing distance tending to increase the likelihood that events will be part of the same whole or within the same boundaries; and (*b*) the probability of simultaneous arousal, the likelihood of events being included in the same whole increasing with the probability of their simultaneous arousal (Principle IV).

This means that anything which increases the probability of activating either or both of two points will increase the probability of their occurring together, for the higher the probability of their occurrence, the more likely they are to occur together.

Duration of Activity and Action Decrement

The repeated activation of the same structure at short intervals leads to activity decrement (Principle V).

The spread of activation will depend not only on distances between the parts of a structure and the pattern which determines the occurrence of multiple input at certain points, but it will also be influenced by the state of the to-be-activated structure. There is considerable evidence to indicate that the repeated activation of the same structure tends to produce a temporary reduction in activity; that is, activity results in some sort of change in the state of the system so that it is less reactive. This is what Lewin called *satiation* (**21**) and Hull, *reactive inhibition* (**16**). Köhler has provided evidence of figural after-effects which points to a similar process (**19**). And more recently Walker and his associates have also confirmed the existence of a decrement in activity as a result of activity (**37**).

It would appear in general that the same conditions which result in developing clear foci of activity and sharp boundaries (IV) will tend to speed the onset of decrement. This suggests that short distances between the parts of a structure should lead to decrement, provided either that the parts are interrelated in such a way that they activate each other, or that input to the parts from some external source continues so that parts are activated repeatedly and simultaneously. However, the persistence of activity within a structure is not simply determined, for two consequences of distance between parts work in opposed directions. On the one hand, repeated activity at the same point is more likely to occur at short distances between parts, and hence to produce decrement. But it is also true, on the other hand, that great distances may reduce the probability of activation so much that activation ceases. The condition of maximum duration of activity is to be expected, therefore, at some distance between parts which is great enough to prevent immediate onset of decrement and yet small enough to provide relatively high probability of continuing transmission of activation from one part of the structure to another, under the existing conditions of input to the structure.

The application of this principle suggests that a simple stimulus object like the conventionalized drawing of a face would yield not only a simpler and more circumscribed activation pattern than will the actual presence of a person, but that the former stimulus should result in a more prompt perceptual act and a more rapid onset of decrement, so that the perceptual act should drop from "attention" more promptly.

THE DESCRIPTION OF SELECTED STRUCTURES

We turn now to the task of describing selected structures that are implied by familiar relational concepts such as

similarity, opposites, complements, antecedents, and consequents. These classes of relationship are not sharply delimited nor have they always been defined in the manner here proposed. We believe, however, that the structures to be described are common ones, and that the particular terms used as labels are not without precedent. As already indicated, it is our intention to describe these patterns in terms of the concepts of position and distance, as previously defined. And in each case, the question will be: How does this arrangement affect the course of activation when the structure is aroused at different points? Obviously, a very large number of structural arrangements and of input patterns may be conceived. It has been necessary, therefore, to limit the task to a description of the structures mentioned above and to a consideration of the course of activity in such structures when certain simple input patterns are operating: activation at one point; at two points different distances apart, resulting in such outcomes as assimilation, contrast, or algebraic summation of opposites; and at three points, which will produce resultants of the kind that Heider has called balanced and unbalanced (**11**).

Similarity Structures

It has been common practice to define similarity conceptually in terms of the sharing of common properties. Sometimes this means that similarity between two events is described in terms of their distance apart on the same continuum. Again, it may refer to the number of continua (or properties) that the events have in common (**6**). Obviously some combination of the number of shared properties and the amount of each such property involved in the complexes would provide a more sensitive index of similarity than either alone. However, we shall consider at this time the simple conception of similarity defined in terms of distance between points on a continuum, for the more complex structure raises other problems, such as the organization of the separate properties within the complex, which must be given more detailed elaboration elsewhere.

To say that a common property is shared by two events means that the events lie on the same continuum. And in the words of Poincaré, ". . . a system of elements will form a continuum if we can pass from any one of them to any other by a series of consecutive elements such that each is indistinguishable from the preceding" (**30**, p. 52). In such a series some position A is indistinguishable from B and B from C, although A is not equal to C.

It is assumed that distances are short within a continuum, so that the probability of activation at any point in the continuum by activity at other points tends to be high. However, as the continuum comes to include more distinguishable positions, and hence to imply a greater number of events between the activation of one end and the transmission of the activation to the other end, the distance will be increased.

Now it should be recognized that the property represented by a continuum may be anything at all which the individual has abstracted from his experiences and structured in this fashion. This means that it may be blueness or brightness or other properties assigned to physical objects, but it may also be any of the qualities that we attribute to human beings, such as friendliness, conservatism, honesty, coldness, or aggressiveness, any one of which may be regarded as a simple property varying in amount

and made up of a series of ordered positions without gaps between them.[5]

Opposites

At some stage a continuum may become so highly differentiated that the distance between the end points is greatly increased and subcategories develop within the more inclusive continuum. When this has occurred, moving from one end of the continuum to the other involves passing through a zero point or boundary which separates the emerging subcategories. Thus warm and cold within the dimension of temperature, or clean and dirty within the continuum of cleanliness, exemplify emerging subcategories which are in contact at a zero point. Such subcategories are usually called opposites.

The emergence of the opposites relation from a similarity continuum is implied in studies which have revealed that this relation appears relatively late in the individual's life history, as compared to similarity (**39**, p. 344). It is also of interest in this connection that various writers, including Freud (**9**), have noted that the same word may serve to represent a property and its opposite in ancient languages, such as Egyptian or Latin, while modern languages tend to use different words for these relationships. Latin provides examples like the word *altus*, meaning both *high* and *deep*, or *sacer*, to be translated as *holy* or *accursed*. Primitive speech is said to refer rarely to opposites, though relations of similarity are frequent (**38**), which again suggests the derivative nature of opposites relations.

But it must be recognized that opposites structures may also develop when a common property is abstracted from two initially unrelated continua or categories which have become associated to form subcategories within the abstracted dimension. The affective continuum, made up of positive and negative affect, may possibly emerge in this way, although the facts are not clear. Neurologically, positive and negative affect appear to depend on separate centers (**24**), and this suggests, though it does not prove, that the relation between them has been constructed by learning rather than initially given. On the other hand, early emotional reactions have been said to be undifferentiated excitement with the pleasant (approach) and unpleasant (avoidance) patterns emerging at a later date (**4**, p. 87).

Complements

Whatever the origin of the pattern of opposition, it may be regarded as intermediate in its characteristics between the similarity structure, within which distances are shortest, and those structures called "complementary," where distances are greater. The latter are composed of parts which are not necessarily related by a continuous series but which are nevertheless separated by some finite distance. Moreover, together the parts constitute a whole or they produce some common consequence. This is to say that complements are associated, even though not similar in the sense of lying on the same continuum and sharing a common property. Thus a figure and the background without which there is no figure, the concepts of the role of leader and followers, of men and women, may be thought of as pairs of events whose underlying relationship is usually of this kind.

[5] It is irrelevant for present purposes that the structure of personality traits is in fact more complex and that simple continua are rare. People may actually have such oversimplified beliefs about personality structure even though the psychologist regards the belief as inaccurate.

Antecedents and Consequents

When one event is responded to as preceding another, the psychological distance between them is greater than that between complements. The magnitude of this distance is a function of the length of the temporal interval between the occurrence of the events in past experience, as well as of the frequency and consistency of this experienced relation. Moreover, the distance from antecedent to consequent will typically be shorter than that from consequent to antecedent. This assumption is based on the fact of the relatively greater strength of forward than of backward associations (**13**, p. 622).

There are many situations that presumably involve structures of this kind. For example, a man and the acts which he performs will sometimes take on the antecedent-consequent relation. Heider (**10**) has presented interesting speculations about this matter, and has suggested that although these events may be a sequence, the man and his acts tend to be treated as a whole: the acts are characteristics of the man rather than separate events. We would suggest that it is necessary in any particular case to determine the distance between the two events, the probability that the activation of the concept *man* will elicit the concept of the *act* in question, as well as the probability that the activated notion of his *act* will elicit the concept of the *man*. As the distance becomes greater and the relation more asymmetrical, it will take on the properties of the antecedent-consequent relation. It is evident that precise boundaries between the complementary relation and the antecedent-consequent relation cannot be established. In this, as in all distinctions between the structures described, we are dealing with relative distances, so that it is simply a matter of convenience that leads us to apply different terms to relations which involve different relative distances.

Abstracted Relations

The discussion has been focused so far on the nature of certain concrete relations between events, but it is important to note that such relations may be conceptualized. Boring is making this distinction between a relation and the concept of it when he remarks, "A succession of ideas is not equivalent to an idea of succession" (**3**, p. 575). The idea of succession is an abstraction of one aspect of an activation pattern in which some event follows another. In the same way, similarity between two events is not the same as the idea of similarity. A simple similarity structure means that two points share a common property, in the sense of lying on the same continuum. But the pattern resulting from activation of two such points on the same continuum may have become related to another structure which, when activated, is the conceptualization of similarity. An abstraction is, therefore, just another event, resulting from the activation of a structure, but it is important to remember that distances within a *concept* of similarity-between-*A*-and-*B* will not necessarily be the same as the distance between *A* and *B* on the dimension from which this abstraction was derived. This does not mean that principles governing a certain relation and the concept of that relation are different, but rather that the precise structure of a concept of a relation must be determined, and not assumed to be the same as that of the referent structure.

Complex Structures

In order to make as clear as possible the essential features of the concept of structure as here presented, similars, opposites, complements, antecedents, and consequents have been treated separately as though two given events were related in only one of these patterns at a time. The fact is that the different aspects of complex structures may have different and multiple relations. Thus, the concepts of leaders and followers, though complementary, may also share common properties, such as having similar attitudes toward certain policies. Moreover, two complexes may share more than one dimension or they may have more than one complementary property. This means that the component aspects of two complex events may be different distances apart, so that the distance between the complexes themselves must be a function of the combination of these multiple relationships. It is suggested that the commensurability of the distances on different dimensions depends on the combination of the probabilities of activation implied by each relationship. In other words, if complex structures, A and B, have positions X_a and X_b on continuum X and positions Y_a and Y_b on continuum Y, then the distance from A to B is a combination of the probabilities that activation of X_a will result in activation of X_b and that Y_a will produce activation of Y_b.

ACTIVATION WITHIN SPECIFIC STRUCTURES

Assimilation and Contrast

The activation principles which have been stated must now be applied in order to illustrate the kind of resultants that may be produced within specific structures when activated at certain points. The first notion to be discussed is the familiar one[6] that at short distances between the points of input the result will be assimilation, and at somewhat greater distances, contrast.[7]

Despite the different shades of meaning that have been given the term *assimilation*, all uses emphasize similarity between processes in one way or another. Sometimes assimilation is known by the fact that the classification of events is the same; again, it is regarded as the incorporation of one event by another (**29**, p. 6); or it refers to the fact that two stimuli produce the same response (**31**, p. 8); or events are perceived as the same (**20**, p. 95). We shall apply the term to that resultant of two-point activation which is intermediate in some respect between the results that appear when either one of the points is activated without the other. In other words, assimilation has occurred when distance between the points is reduced by their simultaneous activation, so that a tall man looks smaller and a small man taller if they are together than when alone. On the other hand, contrast implies that the distance is exaggerated when two points are activated at the same time, with the consequence that the tall man looks taller and the small man smaller when they are together.

The recent studies of Sherif, Taub, and Hovland provide one illustrative test of the hypothesis under conditions which systematically vary the distance between structures activated, in order to determine whether or not

[6] See, for example, Woodworth (**39**, p. 507; 569), Koffka (**17**, p. 502), Krech and Crutchfield (**20**, p. 95).

[7] Under conditions that cannot be elaborated, summation may possibly occur at the shortest distances. In this case either stimulus would be judged greater in the presence of the other than when alone.

there is a shift from assimilation to contrast as the distance increases (34). A series of weights was judged, first without an anchor and later following an anchor weight. In one condition, the anchor was equal to the heaviest of the original weights, and in another it was equal to the lightest. The judged heaviness of the weights *increased* when the heavier anchor preceded the weight being judged and decreased when the lighter preceded. This is the result that would be expected if the perception of either of two events, with a small distance between them, lies between the position of the two judged separately. In another portion of this same study the authors showed that as the difference between the anchor and the weights of the original series was made still greater by an increase in the weight of the anchor, the judged weight of the original stimuli *decreased*. When the anchor was farther away from the weights in the original series and lighter, the original weights were judged heavier. This is the common observation of contrast made in the context of adaptation level theory.

Further evidence has been presented by these authors suggesting that reactions to communications about social issues follow these same principles, for statements about prohibition which fell within short distances of the individual's own position were seen by him as closer to his views, while those beyond this range were seen as farther away from his own position "than was actually the case" (14). In other words, there was a disposition to exaggerate the distance between own view and that of others in the latter case (contrast) and to underestimate it in the former (assimilation).

Although this kind of evidence supports the notion that distance between activated points is a factor in determining whether assimilation or contrast occurs, it remains to show why this should be so in terms of the assumptions made in this paper about distance and activation. We must ask what differences in the activation pattern would make us predict assimilation at short distances and contrast when the distances are longer.

The theory. The essential feature of the theory being proposed to account for this relationship is first of all the fact that at short distances simultaneous activation of two points A' and A'' by stimuli S' and S'' will result in multiple input to, and therefore maximum probability of arousal, of points lying between those positions that would be activated by the presence of either S' or S'' alone. This effect of multiple input at short distances follows from Principle III. Such a pattern of activation should result in a judgment of A' or of A'' which lies between the positions that they would take if presented alone.

When the positions of A' and A'' in the ordered series are farther apart, the number of intermediate points with multiple input decreases so that the activation surface[8] or pattern of probabilities of activation becomes bimodal, with two points of maximum probability of activation separated by points with lower probabilities. In this case, the judged position of either A' or A'' will be a function not only of the points of maximum activation on the surface but also of the number of events judged to intervene between

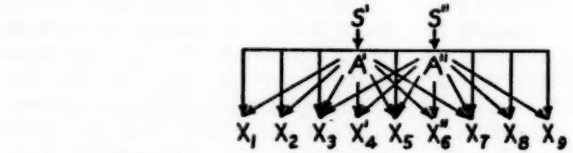
[8] From this point on, the phrase *activation surface* will be used to refer to a pattern of probabilities of activation resulting from input to a given structure at certain points. The line labelled *combined probabilities* in Fig. 2 and 3 represents the surface resulting from activation of the structure at points A' and A''. Similarly, the curves of Fig. 4 and 5 represent activation surfaces.

the two maxima. According to Principle IV, the number of events between any two points is an inverse function of the probability that adjacent points will be activated simultaneously and a direct function of the distance between the points, when that distance is inferred from the position of the two stimuli presented at different times, so that there is no multiple input. It will be shown that at longer distances where the resulting surface is bimodal but still determined in part by the multiple input to intermediate points, the number of events, and hence the distance, will be increased disproportionately. This exaggeration of the number of events intervening between points of maximum activation results in contrast because the positions of the two maximum points will be seen as farther apart or separated by a greater number of events.

Development of activation surfaces as a function of distance between points of input. In order that this theory may be made clear it is necessary to show how different activation surfaces arise as a function of distances between the relative positions of input on some dimension. In Fig. 2, 3, 4, and 5, S' and S'' are stimuli which activate the continuum, A, at points A' and A'' respectively. Xs are other structures related to A at various distances. Now Xs, like As, represent any psychological process whatsoever—concepts, names, affective responses—that are activated with some probability by the arousal of A; they may or may not constitute a continuum; and they will be related to each other in varying degrees, depending on their developmental and activation history. However, if A is a continuum with the result that distances within A are short, and if distances between As and Xs are short, it should follow that Xs will have tended to become an ordered series connected by relatively short distances. This must be the case because Xs will have frequently been aroused at the same time as a result of activity in A. As and Xs in the accompanying figures are, then, simply different parts of the structure which are represented as having asymmetrical relations (connections in the direction from A to X). This means that activation of A will be followed by activation of Xs.

Figure 2 presents a schematic picture of relations existing between S' and A', between S'' and A'', and between points on A and certain Ss. It will be noticed that a given A point is represented as being related to several Xs. X'_4 and X''_6 represent direct, maximum probability responses to the activation of A' and A'', respectively. The connections of A' to X_1, X_2, X_3, X_5, X_6, and X_7 and of A'' to X_3, X_4, X_5, X_7, X_8, and X_9 are structural relations whose activation produces generalized reactions that have been developed in the following manner. Since distances within a continuum are assumed to be short, it must follow that when any point A' has been activated in the past and followed by activation of some structure X', other points (A_ns) on A will also have been aroused at at the same time, the probability of this simultaneous arousal decreasing with increase in the distance of the given A point from A'. As a consequence, structural relations between these A points and various Xs will have developed,[9] their distance being an inverse function of the distance A'–A_n. Though separate connections from A to X are drawn for

[9] See page 328 on restructuring and learning for the discussion of conditions of building a relation such as this.



$$S' \overset{p}{\cdots}> X \left\{ \begin{matrix} p(S' \cdots A') \\ \times \\ p(A' \cdots X_n) \end{matrix} \right. \rightarrow .09 \;\; .45 \;\; .63 \;\; .72 \;\; .63 \;\; .45 \;\; .09$$

$$.09 \;\; .45 \;\; .63 \;\; .72 \;\; .63 \;\; .45 \;\; .09 \leftarrow \begin{matrix} p(S'' \cdots SA'') \\ \times \\ p(A'' \cdots X_n) \end{matrix} \Bigg\} S'' \overset{p}{\cdots}> X$$

$$.09 \;\; .45 \;\; .66 \;\; .85 \;\; .86 \;\; .85 \;\; .66 \;\; .45 \;\; .09 \quad \text{Combined Probability}$$

FIG. 2. Activation surface derived by combining probabilities of activation to each point on X from all related points on A. S' and S'' are stimuli activating points A' and A'' on continuum A. Various points are related to other points with the probabilities indicated below:

$S' \rightarrow A' = .9$	$A'' \rightarrow X_5 = .7$	$A' \rightarrow X_1 = .1$
$S'' \rightarrow A'' = .9$	$A'' \rightarrow X_7 = .7$	$A' \rightarrow X_7 = .1$
$A' \rightarrow X_4 = .8$	$A' \rightarrow X_2 = .5$	$A'' \rightarrow X_3 = .1$
$A' \rightarrow X_6 = .8$	$A' \rightarrow X_6 = .5$	$A'' \rightarrow X_9 = .1$
$A' \rightarrow X_3 = .7$	$A'' \rightarrow X_4 = .5$	
$A' \rightarrow X_5 = .7$	$A'' \rightarrow X_8 = .5$	

convenience, the more accurate picture would represent a sheaf or cone of relations without gaps in points on A that are connected with Xs.[10]

The nature of the activation surface at X will depend on the input to each X from all A sources, combined according to the assumptions of Principles II and III. The activation surface of Fig. 2, labelled *combined probabilities*, is obtained when the distances between the various points are assumed to be those indicated in the figure caption, when input to the two points on A are close enough together to provide multiple input to all Xs except those on the end of the continuum, and when the stated combining principles are applied to obtain the probabilities.[11] For example, in Fig. 2 in the row marked $p(S' \cdots > A') \times p(A' \cdots > X_n)$, the probability below X_1 (0.09) is the product of the probability that S' will activate A' (0.9) and that A' will activate X_1 (0.1). In the same row, the probability under X_2 (0.45) is the product of $p(S' \cdots > A')$ and $p(A' \cdots > X_2)$ and so on for this row and the next one which involves probabilities deriving from S'' activation. The row below the line (combined probabilities) is the combination of multiple input at each X point. For example, X_3 has a probability of arousal by S' equal to 0.63 and by S'', 0.09. The combination $[1 - (0.37 \times 0.91)]$ is 0.66 (Principle III).

Under these conditions, it is clear that high probability activation occurs at points between X' and X'', and that the probabilities fall off rapidly on either side of these maxima.

[10] We have not taken account of possible input to Xs from points on A other than A' and A''. If this were done, the probabilities of the intervening points would be even higher.

[11] Obviously such a surface will change not only with change in distance $A' - A''$, but also with different values of each distance in the structure. Also it should be noted that, as the probability values approach unity, less change will be produced by the existence of multiple input to any point.

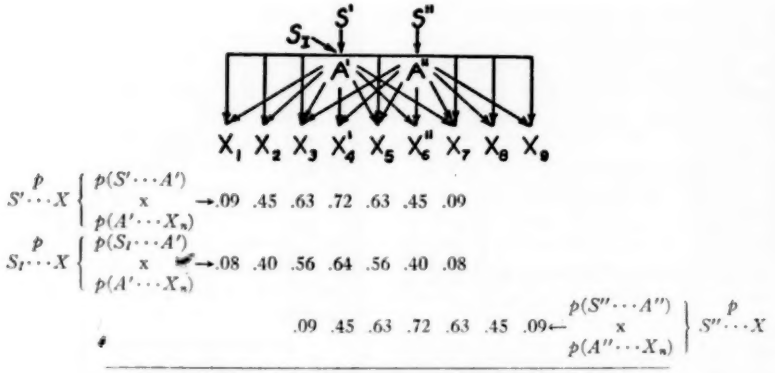


FIG. 3. Activation surface derived from combining probabilities of activation to each point on X when there is additional input to X from instructions (S_I) *to judge* S'.

Furthermore, the points between X' and X'' are activated with higher relative frequency than any others on the surface. This assimilation surface involves, then, maximum probability of activation at points intermediate between those positions that would be maximal if S' or S'' were presented and judged alone.

But a symmetrical surface of this kind results only if there are no sets, instructions, contexts, or other factors that provide differential input at A' and A''. Figure 3 suggests the effects of such differential input on the surface. Suppose the subject is told to judge the intensity of S'. It is suggested that such an instruction produces additional input to A', deriving from a motivation system set up by the instructions. This added input, identified as $S_I \cdots > A'$ in Fig. 3, is assumed to be equal to 0.8 and will have the effect of skewing the activation surface and of producing maximum probability of arousal at a point which is closer to X' than in the case of Fig. 2. Instructions *to judge* S'' would skew the surface in the opposite direction.

If the same principles of combining input at various points, the same distances within the A dimension and between A points and X points, and the same instructions to judge S' are assumed, we obtain the series of surfaces of Fig. 4 and 5 as the distance between the two points of input to A is increased. It will be seen that in

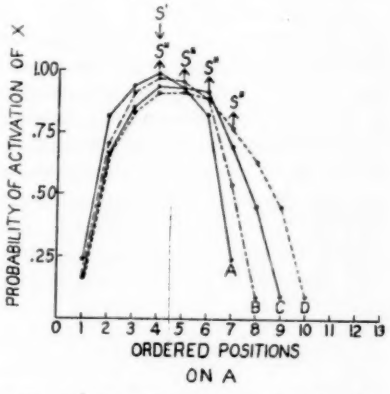


FIG. 4. Graphic representation of activation surfaces resulting when distances between points of activation are short. Surfaces *A*, *B*, *C*, and *D*. S' and S'' represent input points for the different surfaces.

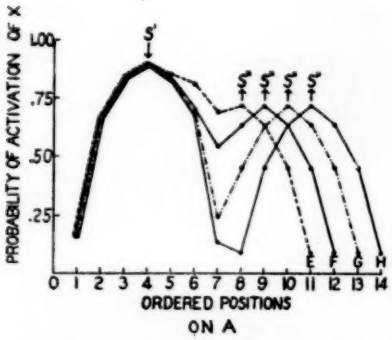


FIG. 5. Graphic representation of activation surface resulting when distances between points of input are greater. Surfaces *E*, *F*, *G*, and *H*.

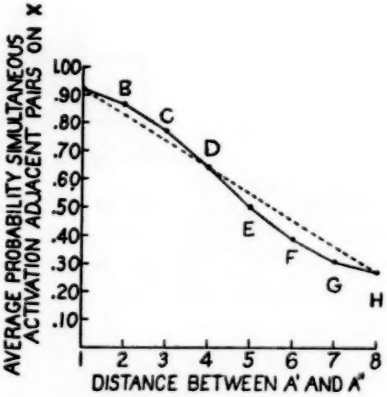


FIG. 6. Relation between difference in judges position of S' and S'' when presented separately (distance $A' - A''$ inferred) and the average probability of simultaneous activation of adjacent positions between input points for activation surfaces *A* through *H* of Fig. 4 and 5. Dotted line represents the relation of distance and average probability (inverse of relative number of intervening events) if the events increased directly with distance. The solid line results from plotting probabilities for the two-point activation surfaces.

passing from surface *A* to *H*, the breadth of the surface increases, bimodality increases, and the values of the probabilities of activation at intervening points decreases. The relative number of events occurring between points of activation must therefore increase because of increased distance and because adjacent points will not so often be activated simultaneously (Principle IV).

Change in the relative number of distinguished events as a function of distance between two points of activation. Figure 6 represents an estimate of the change in the relative number of events occurring between two input points with increase in the distance between the points, this distance being inferred from the difference in the judged positions of the points when each stimulus is presented and judged alone. In Fig. 6 the average probability of simultaneous activation of those adjacent pairs of points lying between input points is used as an index of the relative number of events (Principle IV). Operationally, the average probability that adjacent *X*s will be activated is assumed to be equal to

$$\frac{\Sigma(p_{x'} \cdot p_{x'+1}) + (p_{x'+1} \cdot p_{x'+2}) \cdots (p_{x''-1} \cdot p_{x''})}{N}$$

where $p_{x'}$ = probability of activation of x'; $p_{x'+1}$ = probability that X adjacent to X' is activated; $p_{x''-1}$ = probability that the X adjacent to X'' and lying between X' and X'' will be activated; and N = number of adjacent pairs between X' and X''.

This average probability of simultaneous activation was calculated for each surface, *A* through *H*, and the points joined by the solid line represent the average probability value for a given surface at the input distances from which that surface resulted (see Fig. 4 and 5). The dotted line joins the point derived from surface *A* (zero

distance between input points) and the point derived from surface H (no overlapping input to intermediate X points). When the solid line is above the dotted one, this means there is a smaller average probability of simultaneous activation of adjacent points, and hence fewer intervening events for that surface than would be expected if the number of events were a linear function of input distance. If the solid line falls below the dotted one, there are relatively more intervening events for the surface.

It will be seen that the curve drops at an accelerated rate for surfaces B, C, and D, and that it falls at a decelerated rate for D, E, F, and G. This implies fewer events per A'–A'' unit of distance for the surfaces deriving from short distances between input points, and relatively more events per unit for the longer distance surfaces. Within the first group assimilation occurs; within the second, contrast,[12] for as a result of this disproportionate increase in the number of events at the longer distances, the judged position of the two stimuli will be shifted toward the ends of the continuum to produce the contrast effect.

The question inevitably arises how these activation surfaces come to produce a single response, such as the judgment of the position of S', which in the contrast condition will be displaced toward the end of the continuum. We must assume, without presenting the justification for the assumption, that this pattern of events (the activation surface) has become related to a structure representing some such response as *S' has low intensity of value E*. Another activation pattern consisting of two maxima and fewer intervening events would be more closely related to a point of the structure whose activation produces another judgment. But such responses will be complexly determined by input from points of maximum probability of activation on X combined with the process representing the number of intervening events. This suggests that contrast-determined responses should have longer latency than those resulting from assimilation.

Algebraic Summation and Cancellation Effects

It will be recalled that opposites structures involve continua which have developed subcategories as the distances along the continuum are increased. In considering the influence of such arrangements on the course of activation, we must ask first whether

[12] Unfortunately, there is not space to discuss the relation of adaptation level theory to this formulation. In brief, adaptation level is conceived as that X point (X_{AL}) which has the largest number of high probability connections from points on continuum A. X_{AL} will be the point or points directly activated by the As most frequently aroused in the past, because as a result of this frequency X_{AL} will have had the best chance of becoming connected with all A points. If A has been activated at a number of points, those X positions near the center of the series will have the highest probabilities of arousal from any point on A, because such central points are closer on the average to other points on the continuum than are points at the end of the continuum. It is for this reason that the AL tends to lie at an average value of the experienced intensities of a stimulus. Given such a structure, the activation of any point A_n will elicit not only its own X_n with high probability but also X_{AL} through the generalized connections. In this way an activation surface is set up, the properties of which determine whether X_n and X_{AL} are assimilated or contrasted in exactly the same fashion that a surface produces assimilation or contrast when there are two *external* sources of input to A. The effect of this on the judgment of a single stimulus has been neglected for the sake of simplicity.

assimilation and contrast occur within such structures.

Take, for example, the opposites structure underlying positive and negative evaluation or affect. Continuum *A* is activated by input at two points. Suppose that the *X*s most readily elicited by activation on one side of the zero point of this continuum represent unpleasant affect, and on the other side, pleasant affect. The mid-category of this series will refer to zero affect, which is a definite position or structure whose activation produces this response. Insofar as there is generalized input from points along the positive-negative continuum to intermediate *X* structures including the zero category, assimilation or contrast will result for the same reasons and under the same conditions as they appeared within the simple similarity dimension.

But the result will appear as algebraic summation of the two activated points. Thus, if one activation point lies near the extreme negative end of the continuum and the other point activated at the same time is near zero but on the positive side, the intermediate point of maximum activation should be negative. Conversely, with high positive and moderately negative points activated, the result will be slightly positive. But if the activation points are equidistant from zero, then the zero category will be the one most probably activated. In other words, the phenomenon of algebraic summation of positive by negative affect is a special case of the more general theory of assimilation, and depends on (*a*) the existence of ordered arrangements of positions on a continuum, (*b*) input from the two points of activation to intermediate points, and (*c*) the existence of subcategories within the dimension such that different responses are produced if the point of maximum activation is on one or the other side of zero.

There is some evidence that such summation of positive and negative affect actually occurs. For example, Rosenberg's (**32**) successful prediction of attitudes toward segregation from the combination of positive and negative consequences related to segregation implies such summation. And Osgood and Tannenbaum's evidence for their congruity theory of attitude change also implies this same pooling of affect organized around a concept. Although they emphasize the assimilative aspect of the process, they do recognize that assimilation may not take place, when they say:

> The amount of incredulity produced when one object of judgment is associated with another by an assertion is a positively accelerated function of the amount of incongruity which exists and operates to decrease attitude change, completely eliminating change when maximal (**25**, p. 47).

In other words, "incredulity" tends to appear when the affect attached to a statement attributed to some source is distant from the level of affect (or evaluation) attached to the object about which the statement is alleged to have been made, so there is no assimilation.

Presumably contrast may also occur within an opposites structure when the distance is greater, provided the points activated are not at the ends of the continuum. Contrast is obviously impossible in this latter case, because activation cannot be shifted to more extreme points on the continuum even though the activation is of the sort that usually leads to contrast. The extreme response is given when the stimuli are presented alone; it cannot be any more extreme when the stimuli occur together.

Balanced and Unbalanced Structures

Heider (11), Newcomb (23) and others have used the language of Lewinian field theory in discussing "strains toward balance and symmetry." More recently, Cartwright and Harary (7) have described the same situations in the more general terms of graph theory. It is our hope that the same material may be handled ultimately by the concepts formulated in this paper.

Let us describe a structure which appears to have the properties of balance. A friend (F) has in the past often elicited in an experiencing individual strong positive feelings and on rare occasions negative feelings. Assume that these experiences have resulted in building the structural arrangements of Fig. 7. F is close to P (strong positive affect, $p = 0.9$); F is far from N (negative affect, $p = 0.1$). Positive and negative affect lie on an opposites dimension, the ends of which are represented as being far apart ($p = 0.1$). The relations are symmetrical.

On some occasion the friend is present as a stimulus which is assumed to provide cues for the direct activation of structures F, N, and P, the probability that S will activate each of these structures being equal to 0.9. What will the outcome be?

On the cycle following input to these points, F and P will each be activated with a probability of 0.83, while the probability of N will be 0.17. These values are derived by applying Principles II and III to the situation. For example, the probability of the activation of P from the direction of F is the product of the probability that F will be activated by Sf (0.9) and that P will be activated when F is active (0.9). This is equal to 0.81. The probability that P will be activated from the direction of N is the product of 0.1 and 0.9, and is equal to 0.09. Combining this multiple input (0.81 and 0.09) yields a probability of 0.83. In similar fashion, the probability of activation of N and F may be calculated for this cycle.

The obvious fact here is that F and P are activated with higher probabilities than N, and therefore will more often be aroused at the same time (p of simultaneous arousal $= p_F \times p_P$). As a consequence, F and P (the friend and positive affect) tend to be part of the same whole or the same unit event from which N is excluded, because of its distance from the other two structures and the lower probability of its being activated at the same time as they (Principle IV).

This structure is balanced, then, in the sense that (*a*) its activation will tend to result in two events or wholes with relatively clear-cut boundaries, F-P on the one hand and N on the other; and (*b*) the activation should be of short duration because the isolation of the F-P segment from N makes this essentially a simple two-

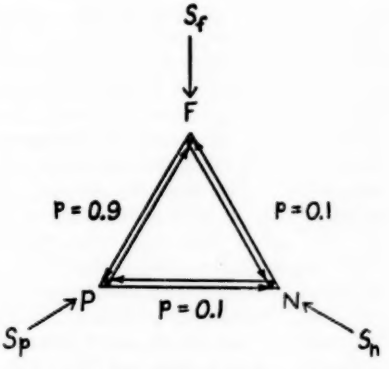


FIG. 7. A "balanced" structure. The ps are probabilities of activation of one point as a result of activation of the point connected with it by a line. Arrows indicate direction of the relation which is in each case symmetrical. Ss are points of stimulus input.

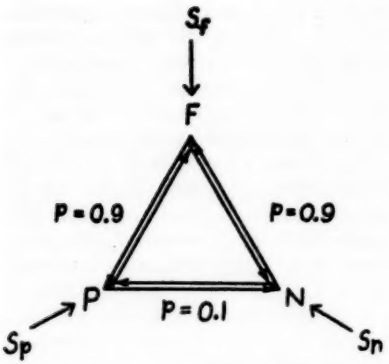


FIG. 8. An unbalanced structure.

part structure consisting of the *F-P* segment and the *N* segment. The mutual activation of *F* by *P* and *P* by *F* would be expected to produce rapid activity decrement because of the simplicity of the pattern and the short distances within this *F-P* segment. Activity within *N* should be of even shorter duration (Principle V).

Figure 8 represents certain aspects of a structure assumed to underlie strongly ambivalent attitudes toward *F*, and is offered as an illustration of an unbalanced arrangement. Its characteristic is that two events which are far apart (*P* and *N*) are both close to a third event (*F*). Thus the friend (*F*) is close to positive feelings but equally close to negative feelings, while *P* and *N* are again distant from each other. This time the activation probabilities on the first cycle are $F = 0.97$; $P = 0.83$, and $N = 0.83$. Given these values, the probabilities are high that these three points will be activated simultaneously and that they will be part of the same whole: $p(F \text{ and } P) = 0.8$; $p(N \text{ and } F) = 0.8$, and $p(P \text{ and } N) = 0.69$. However, despite the fact that the probability of the simultaneous occurrence of *P* and *N* is relatively high, they are distant from each other and so will not so readily become a unit event (Principle IV). The surfaces resulting from the activation of either *F* and *N* or *F* and *P* would be assimilative in pattern. However, any pattern which includes *F*, *N*, and *P* will inevitably lead to diffuse activation, since negative (*N*) and positive (*P*) affect will typically be associated with different structures. Moreover, since in this case, unlike the balanced structure, *N* and *P* are related through *F*, the surfaces, though diffuse, are not clearly separable. As a result, it would be expected that activity within this structure would tend to be maintained because distances are great enough to prevent early decrement (Principle V) but short enough (by way of *F*) to prevent early cessation of activation.

Heider's original discussion of balance described structures in which the terms were people, related by liking, disliking, similarity, causality, and so on. For example, he would regard as balanced a structure in which *A* dislikes *B* and *C*, while *B* likes *C*. This will be seen to have the same form as the structure of Fig. 7, provided these assumptions are made: (*a*) that the Heider situation represents a cognitive structure in some individual, and (*b*) that the relation of liking is converted to psychological distance between concepts of persons *A*, *B*, and *C*, and hence to the probability of activation of one term of the relation by activation of another one. Then, if disliking implies a distance between persons, it will be a greater distance than that implied by liking. Liked persons are closer to the liker than are disliked persons.[13] Here, as

[13] It is interesting to note in this connection the common root in the phrases to *like*, to be *alike*, and to be *likely*. This suggests a common meaning for liking (positive attitude), being alike (similar or short distance

before, the structure is balanced in the sense that *B* and *C* act as a unit with consequent assimilation, while *A* is isolated. In Heider's unbalanced arrangement, *A* likes *B* and *C* but *C* and *B* dislike each other. Again, one event, *A*, is close to two others, *B* and *C*, which are far apart, and this pattern will have the properties of the schema of ambivalence in Fig. 8.

These examples suggest that the basic characteristic of the arrangements which have been called *balanced* is the fact that they provide the conditions for the development of focused and circumscribed activation surfaces which result in high probability activation of definite reactions and prompt completion of activity within the particular structure. On the other hand, the so-called *unbalanced* structure leads to a more diffuse activation surface and longer continued activation within the structure.[14]

It is of interest that Heider's unbalanced structure has been shown by Kogan and Tagiuri to be relatively rare (**18**). Thus configurations in which a person we like is conceived to choose one we dislike, or in which a person we dislike chooses one we like, are both less frequent than would be expected by chance. This should follow from the fact that in the unbalanced structure events such as these all tend to be activated simultaneously, frequently, and repeatedly with the consequence that the distances between parts will tend to become shorter, other things being equal. In other words, this unbalanced system of relations provides certain important conditions for restructuring and learning which leads to a new structure in which the parts are more closely related and hence tend to form a whole.

Motivation

It should be noted that those properties which lead to imbalance as defined above are the essential properties of a motive structure. The author has stated in an earlier paper (**27**) that when there is a certain degree of disparity between two events which are related or similar in some way, activation tends to be maintained in the system and thus to provide the continuing activity which is one characteristic of the motivated state. This activity continues until some change in the situation reduces the disparity or makes it so great that activity ceases. Thus disparity between the perception of one's status and that of his neighbor may constitute such a system, provided (*a*) that the two events, own status and that of the neighbor, are close enough together to produce a relatively high probability of activation of one term of the structure by activity in the other; and (*b*) that the disparity (or distance) and/or the number of parts are great enough to prevent activity decrement. Stated in terms of the present discussion, this amounts to saying that a motivated state exists when there is distance between events (disparity) great enough to prevent their being reacted to as a single whole with consequent activity decrement, and when at the same time the events are close enough together or related in such a way that disparate terms of the structure are mutually

apart), and being likely (high probability of activation of one by the other).

[14] There are other interesting properties of these structures that cannot be discussed now. For example, a greater average difference in the distances between the same two points via different paths may be an important characteristic of the unbalanced structure; that is, the distance from *A* to *B* may be much greater or less than distance *A* to *C* to *B* in unbalanced structures, but more nearly equal in balanced structures.

activating, perhaps by a common associate such as *F* in the unbalanced structure of Fig. 8.

SUMMARY

This paper has proposed that the course of events within psychological space is determined on any occasion by the nature of the structure, i.e., by the position of parts and the distance between them; and by the points in the structure which receive activation from some source at the moment in question.

Structures involving relations of similarity, opposition, complements, antecedents, and consequents are described in terms of the position of parts and the distance between them. The course of activation within certain of these structures is predicted on the basis of assumptions about the following: (*a*) the relation of distance to the probability of activation; (*b*) the combination of probabilities when there is multiple input to the same point in a structure; (*c*) the combination of probabilities when parts of a structure are arranged serially; (*d*) the number of events that are distinguished within an activation pattern; and (*e*) the development of activity decrement as a result of activity.

Suggestions are made about the way in which these principles may account for phenomena such as context effects, assimilation and contrast, algebraic summation of opposites, "balanced" and "unbalanced" functions, and the persistence of activity in the motivated state.

REFERENCES

1. ASCH, S. E. Forming impressions of personality. *J. abnorm. soc. Psychol.*, 1946, **41**, 258–290.
2. ATKINSON, J. W., & MCCLELLAND, D. C. The projective expression of needs. II. The effect of different intensities of hunger drive on thematic apperception. *J. exp. Psychol.*, 1948, **38**, 643–658.
3. BORING, E. G. *Sensation and perception in the history of experimental psychology.* New York: Appleton-Century, 1942.
4. BRIDGES, K. M. Emotional development in early infancy. *Child Develpm.*, 1932, **3**, 340.
5. BRIDGMAN, P. W. *The logic of modern physics.* New York: Macmillan, 1932.
6. BUSH, R. R., & MOSTELLER, F. A model for stimulus generalization and discrimination. *Psychol. Rev.*, 1951, **58**, 413–423.
7. CARTWRIGHT, D., & HARARY, F. Structural balance: A generalization of Heider's theory. *Psychol. Rev.*, 1956, **63**, 277–293.
8. COOMBS, C. H. Theory and methods of social measurement. In L. Festinger & D. Katz (Eds.), *Research methods in the behavioral sciences.* New York: Dryden Press, 1953. Pp. 470–535.
9. FREUD, S. *Collected papers.* Vol. IV. London: Hogarth, 1952.
10. HEIDER, F. Social perception and phenomenal causality. *Psychol. Rev.*, 1944, **51**, 358–374.
11. HEIDER, F. Attitudes and cognitive organization. *J. Psychol.*, 1946, **21**, 107–112.
12. HILGARD, E. R., & MARQUIS, D. G. *Conditioning and learning.* New York: Appleton-Century, 1940.
13. HOVLAND, C. I. Human learning and retention. In S. S. Stevens (Ed.), *Handbook of experimental psychology.* New York: Wiley, 1951. Pp. 613–689.
14. HOVLAND, C. I., HARVEY, O. J., & SHERIF, M. Some basic processes underlying reaction to communication and attitude change. *J. abnorm. soc. Psychol.*, 1957, **55**, 244–252.
15. HOWES, D. H., & OSGOOD, C. E. On the combination of associative probabilities in linguistic contexts. *Amer. J. Psychol.*, 1954, **6**, 241–258.
16. HULL, C. L. *Principles of behavior.* New York: D. Appleton Century, 1943.
17. KOFFKA, K. *Principles of gestalt psychology.* New York: Harcourt Brace, 1935.
18. KOGAN, N., & TAGIURI, R. Interpersonal preference and cognitive organization. *J. abnorm. soc. Psychol.*, 1958, **56**, 113–116.
19. KÖHLER, W. *Dynamics in psychology.* New York: Liveright, 1940.

20. KRECH, D., & CRUTCHFIELD, R. S. *Theory and problems in social psychology.* New York: McGraw-Hill, 1948.
21. LEWIN, K. *Dynamic theory of personality.* New York: McGraw-Hill, 1935.
22. MEEHL, P., & MCCORQUODALE, K. On a distinction between hypothetical constructs and intervening variables. *Psychol. Rev.*, 1948, **55**, 95–107.
23. NEWCOMB, T. M. Motivation in social behavior. In M. B. Jones (Ed.), *Current theory and research in motivation.* Lincoln: Univer. Nebraska Press, 1953.
24. OLDS, J. Physiological mechanisms of reward. In M. B. Jones (Ed.), *Nebraska symposium on motivation, 1955.* Lincoln: Univer. Nebraska Press, 1955.
25. OSGOOD, C. E., & TANNENBAUM, P. H. The principle of congruity in the prediction of attitude change. *Psychol. Rev.*, 1955, **62**, 42–55.
26. PARKE, N. G., & SAMSON, E. W. Distance and equivalence in sequence space. Air Force Cambridge Res. Lab., June, 1951.
27. PEAK, HELEN. Attitude and motivation. In M. R. Jones (Ed.), *Nebraska symposium on motivation, 1955.* Lincoln: Univer. Nebraska Press, 1955.
28. PEAK, HELEN. Psychological structure and person perception. In R. Tagiuri & L. Petrullo (Eds.), *Person perception.* Stanford, Calif.: Stanford Univer. Press, 1958.
29. PIAGET, J. *The origin of intelligence in the child.* London: Routledge & Kegan Paul, 1953.
30. POINCARÉ, H. *The foundations of science.* New York: Science Press, 1929.
31. ROBINSON, E. S. *Association theory today.* New York: Century, 1932.
32. ROSENBERG, M. J. Cognitive structure and attitudinal affect. *J. abnorm. soc. Psychol.*, 1956, **53**, 367–372.
33. SCHRÖDINGER, E. *What is life?* Cambridge: MacMillan, 1946.
34. SHERIF, M., TAUB, D., & HOVLAND, C. I. Assimilation and contrast effects of anchoring stimuli on judgments. *J. exp. Psychol.*, 1958, **55**, 150–155.
35. STOUFFER, S., GUTTMAN, L., SUCHMAN, E. A., LAZARSFELD, P. F., STAR, S. A., & CLAUSEN, J. A. *Measurement and prediction.* Princeton: Princeton Univer. Press, 1950.
36. THURSTONE, L. L. Attitudes can be measured. *Amer. J. Sociol.*, 1928, **33**, 529–554.
37. WALKER, E. L. The course and duration of reaction decrement and the influence of reward. *J. comp. physiol. Psychol.*, 1956, **40**, 167–176.
38. WERNER, H. *Comparative psychology of mental development.* New York: Harper, 1940.
39. WOODWORTH, R. S. *Experimental psychology.* New York: Holt, 1938.

(Received September 20, 1957)

Psychological Review
Vol. 65, No. 6, 1958

BASIC ISSUES IN PERCEPTUAL THEORY

W. M. O'NEIL

University of Sydney

An attempt to classify modern theories of perception will be used to bring out some major points at issue between them. Some of these issues are epistemological but, as the psychologists' attempts to shelve such questions as nonpsychological have proved unavailing, it is better to face them without too much apology.

Five bases of classification are proposed. These interpenetrate yielding cells, as it were, in a five-dimensional solid. Though the five bases are logically independent, there is an historic tendency for the position taken on one to be associated with that taken on another. Thus some of the cells are recipients of a null class. This fact enables a simpler classification, which nevertheless is best approached through the more elaborate one. Incidentally, the scheme being proposed readily accommodates some other distinctions between types of perceptual theory offered by Koffka (27), Brunswik (12), Bruner and Postman (11), and Boring (7).

Perceiving as an active or as a passive process. The issue is whether perceiving is something done by or something done to the organism. Those who think of it as apprehension, or as the attainment of knowledge in the course of the organism's coping with its surroundings, take an activist position, whereas those who think of it in terms of the reception of stimulation, or as the input of information, are passivist. It is improbable that any contemporary theorist is as thoroughgoing a passivist as was, say, James Mill (35). With the common agreement that perception is selective, there is an admission that the organism is at work on the available stimuli or information. Nevertheless, there is a strong passivist tendency amongst the more behavioristically minded of the contemporary theorists. After Titchener there has not been any strong tendency of this sort amongst the phenomenalists. Within the activist theories there are some important differences. Primary among them is the treatment of perception as reactive or as proactive, to use Murray's terms (37). Those who regard perception as a discriminative response and who stress the impact of needs, motives and the like upon this response are reactivists. The more thoroughgoing purposivists, rarer in perceptual theory than in personality theory, it must be admitted, are proactivists.

The perceived as a real or as a phenomenal object. The issue, an essentially epistemological one, is whether we perceive a real or externally existing object or a representation (or some corresponding impression) of it. The man in the street, who is a naive realist, believes that when he sees a door, he does in fact see an object existing in the external world. A sophisticated phenomenalist such as Scheerer (42) maintains that a door existing in the external world reflects patterns of light energies which stimulate the retina, thus giving rise to neural processes which in turn produce a unit in the phenomenal field which represents the door. Though Scheerer and others of similar persuasion differ from Johannes Müller in many important ways, they agree to the principle in his statements: "Sensation consists in the sensorium receiving through the medium of the nerves, and as the result of the action of an external cause, a knowledge of certain qualities

or conditions, not of external bodies, but of the nerves of sense themselves" (36, p. 1065) and "The immediate objects of the perception of our senses are merely particular states induced in the nerves, and felt as sensations" (36, p. 1073).

Early experimental psychology inherited a clear phenomenalist tradition from both sides of its family tree. Indeed, the analytic phenomenalism of British associationism blended quite readily with the analytic phenomenalism of the sense-physiologists such as Bell, Müller, and Helmholtz. The rise of realism in British philosophy in the early years of this century gave some special twists to the tradition, but it was American realism, especially working through behaviorism, which rejected it. However, the behaviorists largely vacated the field of perception. Their prime interest was in effector-based responses, and any interest they had in sensory processes was limited in the main to questions of sensitivity. There was an early promise, made first by the philosopher Perry (39), to give a full treatment of perception in terms of discriminative response, but only recently have serious efforts at fulfilment been evident. Thus it has been left largely to the phenomenalists to cultivate the greater part of this field.

The problem of error in perception or, put the other way, of veridical perception is a genuine one for psychology as well as for epistemology. All too often the psychologist with phenomenalist convictions regards it as not his concern to make out how the organism attains knowledge of the external world; this includes, of course, the scientist attaining knowledge about his subject matter. As a psychologist he is ready enough to confine the organism to an acquaintance with phenomena, yet as an organism theorizing about perception he presumes an acquaintance with both appearance and reality.

Two phenomenalists as different as Titchener and Koffka used the fact of error in perception to distinguish the arena of psychology from that of physical science. Titchener (45) analyzed visual and other illusions in order to illustrate his distinction between experience viewed as independent of and as dependent upon an experiencer. Koffka (27) made his distinction between the geographical and the behavioral environment the more convincing by his description of the dog bounding into a snow-filled crevasse which he took to be solid snow-covered earth. In general the phenomenalists make out a persuasive case that we perceive not real things but appearances, and that we respond to things not as they are but as they appear to be. These propositions, however, make it impossible to deal with or to recognize the fact of error which had so large a part in leading to them. If it were the case that we know only phenomena, there would be no way for us to get to know about error. Only if we truly know the real on some occasions can we tell that on others we have fallen into error. Within the realist position it is not difficult to show how the fact of error in perception can be recognised, though precisely which piece of knowledge is fallacious may be quite difficult to decide. Were realism to make out that such a decision was easy, it would be embarrassed by the fact that scientific progress is so difficult. In accordance with the formula about the whole truth and nothing but the truth, we may distinguish errors of omission and errors of commission. The former is quite easy for the realist to handle. For instance, in terms of perception as a discriminative response, it may be said that the organism has failed to respond to the object or that it has failed to respond differently to different objects. The error of commission is illustrated by the situation where we seem to have

an object of such and such properties before us and yet where other, especially later, experience convinces us that there was no such thing confronting us. The realist, content with the discriminative response view as it is usually formulated, has no answer to the phenomenalist's question: "Where and what was the apparent object?"

The perceived as a term or as a proposition. The distinction being made is a logical and not a verbal one. A term is any property, such as what the word "red" means, or any set of properties, such as what the words "the red piece of paper" mean. A proposition is the predication of one term of another. The words "the red piece of paper is on a gray background" express or symbolize a proposition. In the behaviorist theories, as well as in most phenomenalist theories of perception, the perceived object is treated as a term. Thus the organism discriminates the red paper from its gray background or the perceiver experiences the field as a red paper figure on a gray ground. But if we consider perception as attaining knowledge, at any rate what James (26) meant by *knowledge about*, we need to think of what is known as having propositional form. Facts are not in the ordinary sense things or terms; they are not what can be expressed by means of nouns, adjectives, verbs, or adverbs alone. Facts are what we need sentences to talk about, and knowledge of a fact is judgmental. Those adopting the propositional view have been in recent times few in number and almost always no more than implicit adherents. There being so many who have treated the perceived object as a term, a much greater diversity amongst them can be expected.

Three major conceptions of the percept can be distinguished amongst the phenomenalists. At one end are to be placed those whom Boring (7) calls the *Leipsigers*, and at the other are his *Berliners*. The *Grazers*, kept company by Spearman and a large band of functionalists, are located somewhere in between. The Leipsigers, especially in the purified form of Titchener, agree with the radical behaviorists in being satisfied with simple discrete substantial terms. Titchener's sensations, despite his talk of context, are just as simple and discrete as Watson's stimuli, despite his talk of situations. Titchener had no way of including relationships within the experienced, and a behaviorist who conceives stimuli either as energy sources or as energies is equally handicapped . The earnest attempts of the Hullians to explain transposition phenomena in terms of stimulus generalization show the distaste for the inclusion of relationships among the stimuli. The Grazers found a place in the percept for relations, but did so by regarding them as imported into or imposed upon the situation by the perceiver. Both they and the Berliners agree in admitting relations as well as qualities in the percept. But the two disagree upon how relations get there. For the Berliners they are not the result of some "production process," but are as primary as the qualities related.

There was a distinct inclination amongst the *Akt* psychologists to adopt a propositional view. Brentano's distinction between the "lower" act of ideation and the "higher" act of judgment included a recognition that the object of the latter was propositional. Stout was quite explicit when he said:

> In general, it would seem that a complete object [of consciousness] can be adequately described in language not by isolated words but by propositions capable of being asserted, denied, doubted or assumed. . . . When we are said to perceive or know something this may be taken to express the fact that we perceive or know that something is the case (44, p. 100).

More recent formulations have not been as explicit. But the recent analyses by MacCorquodale and Meehl (31, 32) and Meehl and MacCorquodale (33) reveal that expectancy in Tolman's theorizing is propositional in form. Insofar as expectancy is equivalent to hypothesis, as used by Tolman and Brunswik (47), and as later adopted by Bruner (9) and Postman (40), all four theorists may be claimed to adopt a propositional view. Helson (23), in stating his adaptation-level theory as a general theory of perception, gives some signs of subscribing to this view too.

Descriptive versus abstractive modes of analysis. In offering a characterization of something in a way which distinguishes it from other things, we may resort either to descriptive or to abstractive terms. The former are features of the object actually before us when we inspect it, features that stand up for inspection, whereas the latter are not literally present in the form in which our analysis might suggest they are. The Wundtians recognized most of the time that the elementary sensations with which they characterized a given percept were in fact abstractions. A pure sensation, as they conceived it, is not something that we ever experience. Likewise, the dimensions of experience which have been derived by Boring (6) from the later Titchenerian doctrine of sensory attributes (46) are not components of experience, but the dimensions of a reference frame within which some particular experience may be located. On the other hand, features like figure-and-ground, contour, and gradient of texture are deemed by those referring to them to be the very material or structure of our experience as we have it. They are descriptive terms. Wundt, the early Titchener, and the Leipsigers generally preferred elemental abstractive analysis; the later Titchener, followed by Boring and Stevens and their associates, have adopted a dimensional abstractive analysis; David Katz, Rubin, the Berliners, Gibson and the phenomenologists generally have employed a descriptive and usually structural analysis.

Preferred location of causal conditions. In seeking to give a causal account of perception, the early theorists stressed proximal stimulus conditions. Later there was a considerable swing to distal stimulus conditions, as Brunswik (12, 14) pointed out. But both place the emphasis upon what Bruner and Postman (11) call autochthonous factors, whereas these two, in concert with many others in the last decade or two, have emphasized needs and other related "central" factors. There is, of course, another kind of "central" factor represented by the brain fields of Köhler and Wallach (28) and of Krech (29, 30), and by the cell assemblies of Hebb (22). The classification of perceptual theories contained in Allport's treatise (1) is based primarily upon the determinants stressed in the theory.

It is appropriate at this point to comment upon the unfortunate tendency of psychologists to identify causes with their effects, or to assimilate them. Werner and Wapner (48), in arguing that if both sensory and motor (tonic) processes interact they must be of the one kind, provide an example of assimilation. The widespread resort to dispositional concepts such as attitudes and sets usually involves an identification. No more is said about them than that they have specified observed effects and that they differ from one another in the effects they each have. Operational or dispositional statements are well enough, but the trouble arises when the need for anything more is not felt. It is well enough to identify opiates by means of their soporific effects, but it is misleading to identify them with those effects. An interesting example of this sort of identification may be found in

the instructive controversy between Boring (7, 8) and Gibson (17). Boring, supposing for argument's sake our planet to be more liberally endowed with satellites, asks what we would be perceiving when we perceived the size of a moon. He is not a naive realist, and so he is not satisfied by the reply "Why, the size of the moon we happen to be looking at!" His own studies of the apparent size of our one and only pre-Sputnik moon led him to conclude that major determinants of such a perception are the actual distance, size, and elevation of the moon, the perceived distance of the moon, the actual elevation of the perceiver's regard, and the perceiver's attitude. He goes on, quite reasonably, to suppose that these values may be used as the parameters of some function, ϕ, which would be invariant when the perceived size of the moon is invariant. So far, to adopt a Boring phrase, this is good science. But it is probably only a confusion of cause and effect when he says ". . . then, in judging size, you are perceiving not object size, not retinal size, but ϕ. To discover the object of perception, you have to discover what function of the stimulus is invariant when the perception is invariant" (7, p. 146).

A Threefold Classification

The historical association of views on these five basic issues has been such that a workable division into discrimination theories, phenomenalist theories, and judgmental theories is possible. No one of these is a compact cluster, so that in any general discussion of them some exceptions have to be made. The second cluster is indeed a clear doublet, the rather tough-minded abstractive theorists standing somewhat apart from the more tender-minded phenomenologists. In the sections below each of these types of theory will be characterized in general terms. Attention will be paid to the relative strengths and weaknesses of the discrimination and the phenomenalist theories. Finally, as part of an attempt to bring out what has usually been left implicit in judgmental theories, it will be argued that this type of theory affords a hope of our being able to retain the best of the other two worlds.

Discrimination Theories

Discrimination theorists are ordinarily slightly on the activist side of center. They are ordinarily realists in that the stimulus (wherever it is to be located, distally or proximally, and however it is to be analyzed) is real in some sense and not phenomenal. They are ordinarily given to abstractive analysis. The stimulus to which the response is made is a term rather than a proposition. There is a marked tendency to pack as much as possible into the stimulus, which is scarcely distinguished conceptually from the cause of the response. Graham (19), indeed, disposes of determinants such as sets and attitudes by referring them, at least in experimental settings, to instruction stimuli. Boring, whose theorizing is best thought of as moving from the tougher-minded phenomenalism towards discrimination theory, speaks of the perceiver's attitude as one of the stimulus properties which is a parameter of ϕ.

Apart from any disagreements on specific perceptual problems, a few general distinctions can be made amongst the proponents of discrimination theories. Those with the greater physiological interests tend to be more proximally focused, and to look for perceptual determinants largely in the sensory mechanism. Those who have been most influenced by modern positivism tend to have the more sophisticated views about the stimulus, to have a greater

"focal length," and to favor dimensional analysis through their concern with stimulus continua. Those who are led to their problems by practical considerations—such as the need to establish the perceptibility of signs, signals, displays, and the like—tend to be empiricist in the rule-of-thumb sense.

This type of theory has many attractions. Foremost amongst these is the scope provided for rigorous theorizing and rigorous experimentation. Another, of less certain value, is the avoidance of the bothersome problem of introspection. As the aim of a perceptual experiment within this theoretical context is the testing of limits of discrimination and the seeking of invariant relations between stimuli and discriminative responses, it does not matter what the responses be, whether verbalization, key-pressing, or making matches; and it does not matter how they be established, whether by conditioning or by instruction stimuli. When a verbal response is used, it does not have to be treated as a report. To treat it as a report the investigator must concern himself with what it alleges and not with its own distinctive features as an event. Such a concern raises the nagging doubts about intersubjective corroboration to which the discrimination theorist seems prone. Their avoidance in this way does not, however, preclude the discrimination theorist from dealing with many problems that have often been deemed to be subjective. For instance, it can be argued that, in establishing a subjective or phenomenal scale of brightness or loudness, the subject is being calibrated as a different kind of instrument for application to some physical variable (*vide* Bergmann and Spence, 3).

The discrimination theorist also has the advantage of the phenomenalist in that he can offer some coherent account of error, as Perry (39) and other American realists have demonstrated. However, saying that when in error the organism has made the "wrong" response does not go far enough. It needs to be shown in what way that response is wrong. When the outcome of an animal's having made some response is the survival or the death of that animal, or even when the outcome is a shorter or longer period of delay in obtaining food or a mate, it may be said that the response made was right or wrong. However, there are occasions when an illusion contributes to survival or to a maximization of benefits, but is nonetheless an illusion. What distinguishes it as an illusion is that the seeming knowledge in it is false. This same limitation obtains when this type of theorist attempts an account of knowledge in the sense of our store of knowledge. Apart from the limitation of the dispositional terms employed, for instance, by Hull (25) and later Berlyne (5), no way is provided for a distinction between true knowledge and false knowledge.

The advantages gained by the eschewal of introspection must have offset against them some handicaps accruing at the same time. It would appear helpful to know that chromatic colors disappear in scotopia, and that it is not merely a matter of some one chromatic color replacing all other colors. A purely discriminative experiment could tell us no more than that, apart from any intensity differences, stimuli of one wave length are not discriminable from those of another including a mixture of all wave lengths. We could have no indication whether the central processes following different stimuli were the same or whether these processes were functionally equivalent though qualitatively different. The pattern of verbal responses made with the addition of appropriate instruction stimuli would not

afford a clue to this unless we regard such responses as alleging what is the case, i.e., as being introspective reports.

Finally, a discrimination theory usually involves a renunciation of what seems to some the genuine and important psychological question expressed by Koffka (27) as: "Why do things look as they do?" This question seems possible only if we are willing to consider introspective data and make some form of distinction between the real and the phenomenal. A distinction between tape-measured and subject-measured distance, for instance, does not go far enough. But as soon as the discrimination theorist begins to make the necessary admissions he is in danger of losing many of the advantages he had otherwise gained for himself. Berlyne suggests: "If we think of the perceptions which constitute the 'phenomenal world,' etc., as reactions to stimulation from physical energy-changes, and overt behavior in its turn as a reaction to them, we may be able to enjoy some of the benefits of both points of view" (4, p. 145). However, if perception is taken as a response in the ordinary Hullian sense, there are difficulties arising through there being no effectors to perform it; and if it is taken as a stimulus-producing response or purely theoretical or intervening variable, it is puzzling how we come to know that it has the properties attributed in other theories to the "phenomenal" world.

Phenomenalist Theories

Phenomenalists have a broader spread over the active-passive variable. Contemporary representatives more often than not come down on the activist side, sometimes well out towards the extreme. They are never realists in predominant flavor, although many struggle, as it were, towards realism. Generally speaking, the more distally focused have the stronger realist tendency. In the past they preferred elemental analysis, but now the predominant preference is for descriptive structural analysis. Once the basic classifying and counting had been done by the elementarists, the remaining part of the program appeared tedious and sterile. Phenomenology has afforded a much richer alternative. In both varieties, phenomena are conceived as terms—sensations when the focus is proximal, and objects when it is distal. The favored determinants are stimulus properties (though played down as compared with the discrimination theorists), other phenomena, brain states, and, with the more markedly activist, motives. There is some dispute, however, amongst them as to the legitimacy or profit in using one or other of these. For instance, Gibson (15) seems mainly concerned to find stimulus correlates and little impressed with the need to locate neural determinants, whereas Werner and Wapner (48) center their attention upon the total organismic state. The rocks that have seriously split phenomenalism have been the issue of abstractive versus descriptive analysis and the issue of proximal versus distal focus. Though independent issues, those choosing abstractive analysis have usually chosen a proximal focus, and those choosing descriptive analysis have usually chosen a distal focus.

Though an epistemological history of phenomenalism should go back at least as far as Locke's distinction between primary and secondary qualities, a psychological history can appropriately begin with that part of Müller's doctrine of the specific energies of the sensory nerves which stated that we are aware not of external objects, but of the states they produce in our sensory nerves. Within this doctrine a veridical knowledge of external objects would be attained to the extent that there is some parallelism or isomorphism between the external objects and the states they

produce. When that parallelism breaks down we have error or illusory perception. But how anything about the parallelism or its absence can be discovered is a puzzle. It is not enough to say, as Müller did, that vision is ordinarily elicited by light, and that when it is elicited by pressure on the eyeball there is an incongruity of stimulus and sensation. To say this assumes that we may know light and pressure on the eyeball as other than phenomena. But even were there two sorts of knowledge—the sort we have in experiencing color and the sort we have in knowing that light is impinging on the eye—it is difficult to show how we would relate one to the other and to say in which realm of knowledge this relating occurred (*vide* Anderson, 2).

There is an interesting paradox in the phenomenalism of Müller's sort. Our knowledge of our sensory states must in one sense be veridical, i.e., in terms of the doctrine, we know only these states and can not know other than what is present in them. Yet it almost always seems to be knowledge of external objects, which, according to the doctrine, is a nonveridical impression. Further, what is said to be knowledge of the states of our sensory nerves gives us the knowledge we have of external objects and very little, if any, information about the states of our sensory nerves. The way we are able to get such knowledge is to have those states as the external objects of other sensory states. Müller, in effect, told us that it is not the moon that we see but a state of affairs in the visual mechanism, whereas Boring tells us that it is not the moon that we see but a mathematical function. Both seem to be confusing what we see with the conditions of our seeing.

Though the later phenomenologists reject sensory states located at the organismic surface, their objects are not literally *out there*. Their focus, as Brunswik (14) shows, is not fully distal. The term "intermediate object," which Brunswik used earlier in his work on object constancy, might well be applied with a slightly different meaning to the phenomenal object in these theories. There remains, nevertheless, the impassable gap between the phenomenal and the real. However, the phenomenological approach has the virtue of producing an orderly account of how things look. The now classical work of Katz, Rubin, and Wertheimer and the more recent work of Michotte (34) and Gibson (16) is evidence enough of this. Furthermore, such work has produced data which seem amenable to corroboration and which set what has already been said to be a genuine psychological problem.

Judgmental Theories

Perhaps some form of discrimination theory has greatest appeal to the physiologically minded, and some form of phenomenalism to the psychologically minded, especially when in the ranks of the professional physiologists. Judgmental theories have certainly been propounded most often by the philosophically minded. However, if, as will be asserted here, such a theory can accommodate some distinction of the sort attempted in the contrast between the real and the phenomenal, and at the same time preserve some of the advantages of objective reference attained by discrimination theories, it may well be the type of theory the psychologist will find best adapted to his needs.

Unfortunately, we have no contemporary judgmental theory in sufficiently elaborated form to let us prove these hopes. Bruner (9) and Postman (40) gave separate statements of their joint thinking which constitutes one promising outline. However, much that is relevant to the claims being made is left

implicit in their theorizing. An explication is rendered the more difficult by a more recent paper by Postman (41) which reveals a distinct swing away towards a discrimination theory. A later paper by Bruner (10) extends some aspects of the judgmental treatment but does not relate its terminology to that of the earlier statements. Without asking these theorists to accept any responsibility for what is to be maintained, many things which perhaps they thought best to leave implicit will be made explicit. Then, in the light of that interpretation, some indication will be given of where their theorizing seems to have gone off (or not far enough along) the track favored here. Finally, some promissory notes will be proffered in the absence of hard cash to capitalize the expansion of this type of theory. Bruner, Postman, and their associates have already a great deal of hard cash to the credit of other aspects of their theorizing.

The full course of cognition was said in 1951 to be an hypothesis-information-testing cycle. This conception applied not only to perception but also to thinking such as remembering, imagining, and reasoning. This is an immediate attraction. All too often we are asked to conceive perception in one way and thinking, with all it entails, in so unrelated a way that we remain puzzled as to how what we acquire through perception can be incorporated in our thought.

The central notion is "hypothesis," which in Bruner's later statement seems to be replaced by "category." Hypotheses "serve to select, organize and transform the stimulus information" (40, p. 249); or "stimulus inputs may be sorted, given identity, and given more elaborated, connotative meaning" in terms of categories (10, p. 148). Hypotheses are deemed to vary in strength, or categories to vary in accessibility. But what hypotheses or categories are is a matter left a little obscure. Bruner in general was and is content with a dispositional conception—these are we-know-not-whats recognizable only by their determinants or by their effects. Postman went a little further in saying that an hypothesis is an expectation that such and such is so and so, or that such and such does so and so. He relates this to Tolman's notion of expectancy. MacCorquodale and Meehl have argued convincingly that an expectancy in Tolmanian theory has the form "if (S_1 and R), then S_2"; e.g., "if, when the light flashes, the lever is pressed, then a pellet of food falls into the cup." This, of course, is an action hypothesis which is the sort required in a theory of performance. Where the account puts the emphasis upon cognition, the "response component" may be ignored; thus "if S_1, then S_2." Cognition of whatever type is to be regarded then as a predicating (asserting, denying, supposing, doubting and so on) S_2 of S_1; or, if no imputation of conscious deliberation is made, as a judging of S_1 to be S_2. It is important to stress that S_1 and S_2 may be quite complex, and that a distinction between a judgment and the verbal or other expression of it is intended.

The judgment or predication may be true or false, depending upon whether, in fact, occasions of S_1 are occasions of S_2. In illusion there is a false predication. This arises in several ways, one of which is fallacious inference, though the latter is more prevalent in thinking than in perceiving. In an error of omission S_1 is judged to be S_2 alone when in fact S_1 is also S_3, S_4, etc. Thus we must recognise that there are, first of all and independently of our knowledge of them, the facts. These are the empirical content of the term "real" in the traditional

distinction. When we judge that S_1 is S_2 and in fact it is, we have attained a knowledge of that fact. When we have attained a knowledge of some of the infinite facts confronting us and have failed, by omission and by commission, to attain the knowledge of others, we have the state of affairs emphasized by the term "phenomenal." To say that we know only the phenomenal is true in the trivial sense that we know only what we know. But it should not be interpreted as having more significance than that. It is demonstrable that, in a rough manner of speaking, the moon looks smaller than it really is. Further, if we assume, as some of our forebears did, that the law of visual angle is sufficient for the explanation of size perception, it may be said, equally roughly, that the moon looks bigger than it ought to. To ask, "What is this too small and too large thing that we see?" is to ask the wrong question. It assumes that there is such a too small and too large thing somewhere. As it is not *out there,* it is then concluded that in some sense it must be *in here* or somewhere in between. The question, "What do we see when we see the size of the moon?" is answerable properly not with "the real moon" (for that gives us no way of coping with the anomaly we have noted), nor with "the retinal image of the moon" (for that is contradicted by experience), nor with "an intermediate or a phenomenal object" (for that is a piece of fabrication which leads us into confusion), but with "that the moon is size X," or "that the moon is the size of X." That this visual judgment is false, and that it varies with the position of the eyes in the head, are matters of great interest to the psychologist—but not because he studies phenomenal moons, leaving the astronomer to take care of the real ones.

Frequently sense perception is regarded as having the particular and the concrete as its content whereas thought, apart from its purely reproductive forms, is regarded as being characteristically concerned with the universal, the conceptual, and the abstract. The psychologists prone to make this distinction seem to have forgotten the long-standing arguments about the nature of universals, and not to have learned that the scholastic positions known as realism, nominalism, and conceptualism do not exhaust the possibilities. Discrimination theorists, when dealing with cognitive matters other than perception, are prone to resort to a sort of nominalism: knowledge of universals is merely making the same response, a symbolic response, to several stimuli. Phenomenalists of the elementarist kind tend to follow a similar line, substituting such phenomena as composite images. Phenomenologists in psychology turn regularly to conceptualism, Goldstein and Scheerer (18) affording an example singularly rich with scholastic vestiges. Bruner, in his theorizing about categories, reveals an inclination towards conceptualism. Nevertheless, his discussion has the merit of showing that perception is not confined to the particular, and that a concern with the universal is as characteristic of perception as it is of thought. A clearer recognition that all cognition is judgmental would lead to a rejection of both nominalism and conceptualism without forcing one into the mystification of medieval realism. What distinguishes the universal is that it is predicable of many things, a point recognized by Bruner in respect of his categories. However, this is the case with anything that is predicable, even when it is a so-called concrete particular. Some psychologists seem to think that there are some logical considerations requiring a special class of "things" called concepts. The nomi-

nalists know that there are no such considerations, but the psychologists among them fail to see that speaking of stimulus and response generalization does not take them far enough in accounting for knowledge. It is not that we confuse one member with another of its class, but that we know each of them to be things of the same sort.

The explication given here of the term "hypothesis" (or "category") reveals a difficulty in giving a qualitative account of hypothesis-strength (or category accessibility) which has an important place in the theory. Though the operational criteria provided especially by Postman suffice for the mounting of an extensive and fruitful experimental program, they are not adequate for a full explanatory use of the term. An hypothesis itself cannot vary in strength; S_1 is simply S_2 but never more or less S_2. No ground is gained by saying that the hypothesis is held more strongly unless it can be said what holding an hypothesis is. To say that the hypothesis is used more or less frequently in certain situations does not explain what hypothesis-strength was meant to explain. The same strictures may be made with respect to habit-strength in Hullian theory. Should habits, now defined dispositionally, turn out to be neural structures, then habit-strength could be some variable property of those structures. A judgment may have a similar neural determinant, in which case hypothesis-strength could be given positive meaning. This is a hope, however, with little factual backing at the moment.

The information and test phases in the cycle also need some clarification. At first sight the information phase is a good deal like what we have all been calling perception. Were further consideration to confirm this impression, then this theory would be not so much an account of perception itself as of the wide context of processes in which it is embedded. Further, too much stress is placed by Bruner and by Postman on stimulation as such, that is, the impact of stimulus energy upon the receptor mechanism. It appears important to recall at this point the distinction made by Harper and Boring (21) between cues and clues. What is referred to as information should on some occasions be recognized as a nonperceived but sensorily mediated determinant of perception, and on others as a hypothesis (judged state of affairs) relevant through inferential processes to the hypothesis under test. The former type of information is a cue (which is all that is considered in cybernetic theory), whereas the latter is a clue which may be a premise as well as a mere determinant. It may well be that a similar distinction should be made in respect of the test phase of the cycle, yielding something like reinforcement in that brand of learning theory with which discrimination theories are most readily affiliated, and something like inference in Tolman's theory, which is at least implicitly judgmental. The strengthening of an hypothesis is akin to acquisition in learning, and the weakening of an hypothesis is akin to inhibition and extinction.

The distinction between cue and clue may well help with the resolution of the present paradox of size and shape perception. The bidimensional retina can of itself encompass only visual angle and projected shape. Perception of size should thus be dependent upon access to information about distance, and perception of shape upon access to information about inclination. There is a fair amount of evidence to support the former of these suggestions, though little available that is relevant to the latter. Several theorists, e.g., Koffka (27) and Boring (7), have been led to suppose

that there must be an invariant relation, to put it in Boring's way, between, in the one case, perceived size, perceived distance, and retinal image size. Now an experiment like that of Holway and Boring (24) does not bear on this alleged relation, for no distance judgment was obtained. An experiment like that of Gruber (20) does bear on it; that it falsifies the alleged relationship is ameliorated only by its inherent design defects. Stavrianos (43) failed, despite a commendable persistence, to show that errors in perceived shape were related to perceived inclination. Her experiment, too, has some basic design defects. Nixon (38), in a series of studies free of these limitations, has falsified the hypothesized relationship. The puzzle here would be resolved were it to turn out that this is an "overdetermined" situation in the sense that there is more information, not all of which is congruent, than the minimum required for a given judgment of size or shape. Some of this information is in the form of a judgment of distance or of inclination. This is a clue to size or to shape when it is conjoined with information such as retinal size or retinal shape. It may operate as a clue through some inferential process, as Helmholtz would have maintained. In addition, there may be cues to distance (inclination is a matter of relative distances) which on this occasion do not influence the judgment of distance or of inclination, but which may influence the judgment of size or of shape. If ocular torsion is relevant to the moon illusion, it would be just such a cue: the paradox that Gruber leaves was left also by Boring in respect of that illusion, namely, that the changed apparent size of the moon is due to a changed cue to distance, even though the apparent distance has been inversely affected. The way a cue affects a judgment would not be through some inferential process. Inference seems peculiar to discourse or to knowledge. It is not merely a matter of cause and effect. When we speak of cues, no more than a causal relation is being referred to. The nearness of the horizon moon is possibly the result (through inference) of its appearing so large.

Were a considerably modified notion of response developed, one able to embrace what Woodworth (49) called a "mental" response as well as what he called a "motor" response, the proposal made by Berlyne (4) would have greater merit. As was pointed out above, a pure stimulus act such as he had in mind will not suffice. Nor, of course, is it enough to say that the perceptual response is to be characterized as discriminative. Little responding, whether cognitive or otherwise, is indiscriminate. The kind of response needed is judging that S_1 is S_2. To fit such a concept on to Hullian theory requires rather more general renovations than Berlyne suggests. However, if it can be done, we should have, as he is hoping to have, the best of the two worlds of discrimination theory and phenomenalism in coping with perceptual problems.

REFERENCES

1. ALLPORT, F. H. *Theories of perception and the concept of structure.* New York: Wiley, 1955.
2. ANDERSON, J. Empiricism. *Aust. J. Psychol. Philos.*, 1927, **5**, 241–254.
3. BERGMANN, G., & SPENCE, K. W. The logic of psychophysical measurement. *Psychol. Rev.*, 1944, **51**, 1–24.
4. BERLYNE, D. E. Attention, perception and behavior theory. *Psychol. Rev.*, 1951, **58**, 137–146.
5. BERLYNE, D. E. Knowledge and stimulus-response psychology. *Psychol. Rev.*, 1954, **61**, 245–254.
6. BORING, E. G. *The physical dimensions of consciousness.* New York: Century, 1933.

7. BORING, E. G. Visual perception as invariance. *Psychol. Rev.*, 1952, **59**, 141–148.
8. BORING, E. G. The Gibsonian visual field. *Psychol. Rev.*, 1952, **59**, 246–247.
9. BRUNER, J. S. Personality dynamics and the process of perceiving. In R. R. Blake & G. V. Ramsay (Eds.), *Perception: An approach to personality*. New York: Ronald, 1951.
10. BRUNER, J. S. On perceptual readiness. *Psychol. Rev.*, 1957, **64**, 123–152.
11. BRUNER, J. S., & POSTMAN, L. Perception, cognition and behavior. *J. Pers.* 1949, **18**, 14–31.
12. BRUNSWIK, E. The conceptual focus of some psychological systems. *J. Unified Sci.*, 1939, **8**, 36–49.
13. BRUNSWIK, E. Psychology in terms of objects. Reprinted in M. Marx (Ed.), *Psychological theory*. New York: Macmillan, 1951.
14. BRUNSWIK, E. The conceptual framework of psychology. *Internat. Encyc. Unified Sci.*, Vol. I, No. 10. Chicago: Univer. Chicago Press, 1952.
15. GIBSON, J. J. Studying perceptual phenomena. In T. G. Andrews (Ed.), *Methods of psychology*. New York: Wiley, 1948.
16. GIBSON, J. J. *The perception of the visual world*. Boston: Houghton Mifflin, 1950.
17. GIBSON, J. J. The visual field and the visual world: A reply to Professor Boring. *Psychol. Rev.*, 1952, **59**, 149–151.
18. GOLDSTEIN, K., & SCHEERER, M. Abstract and concrete behavior. *Psychol. Monogr.*, 1941, **53**, No. 2 (Whole No. 239).
19. GRAHAM, C. H. Behavior, perception and the psychophysical methods. *Psychol. Rev.*, 1950, **57**, 108–120.
20. GRUBER, H. E. Relation of perceived size to perceived distance. *Amer. J. Psychol.*, 1958, **67**, 411–426.
21. HARPER, R. S., & BORING, E. G. Cues. *Amer. J. Psychol.*, 1948, **41**, 119–123.
22. HEBB, D. O. *The organization of behavior*. New York: Wiley, 1949.
23. HELSON, J. Perception. In H. Helson (Ed.), *Theoretical foundations of psychology*. New York: Van Nostrand, 1951.
24. HOLWAY, A. H., & BORING, E. G. Determinants of apparent visual size with distance variant. *Amer. J. Psychol.*, 1941, **54**, 21–37.
25. HULL, C. L. Knowledge and purpose as habit mechanisms. *Psychol. Rev.*, 1930, **37**, 511–525.
26. JAMES, W. *Principles of psychology*. London: Macmillan, 1890.
27. KOFFKA, K. *Principles of gestalt psychology*. London: Kegan Paul, 1935.
28. KÖHLER, W., & WALLACH, H. Figural after-effects: An investigation of visual processes. *Proc. Amer. philos. Soc.*, 1944, **88**, 269–357.
29. KRECH, D. Dynamic systems, psychological fields and hypothetical constructs. *Psychol. Rev.*, 1950, **57**, 283–290.
30. KRECH, D. Dynamic systems as open neurological systems. *Psychol. Rev.*, 1950, **57**, 345–361.
31. MACCORQUODALE, K., & MEEHL, P. E. Preliminary suggestions as to the formulation of expectancy theory. *Psychol. Rev.*, 1953, **60**, 55–63.
32. MACCORQUODALE, K., & MEEHL, P. E. Edward Chace Tolman. In W. K. Estes et al. (Eds.), *Modern learning theory*. New York: Appleton-Century-Crofts, 1955.
33. MEEHL, P. E., & MACCORQUODALE, K. Some methodological comments concerning expectancy theory. *Psychol. Rev.*, 1951, **58**, 230–233.
34. MICHOTTE, A. *La perception de la causalité*. Louvain, 1946.
35. MILL, J. *Analysis of the phenomena of the human mind*. (2nd ed.) London: Longmans, Green, Reader & Dyer, 1878.
36. MÜLLER, J. *Elements of physiology*. Vol. II. (Trans. by W. Baly.) London: Taylor & Walker, 1842.
37. MURRAY, H. A. Towards a classification of interaction. In T. Parsons & E. Shils (Eds.), *Towards a general theory of action*. Cambridge: Harvard Univer. Press, 1951.
38. NIXON, M. C. *Perceived shape and slant*. Unpublished thesis, Univer. of Sydney, 1958.
39. PERRY, R. B. *Present philosophical tendencies*. New York: Longmans, Green, 1912.
40. POSTMAN, L. Toward a general theory of cognition. In J. H. Rohrer & M. Sherif (Eds.), *Social psychology at the crossroads*. New York: Harper, 1951.
41. POSTMAN, L. Perception, motivation and behavior. *J. Pers.*, 1953, **22**, 17–31.
42. SCHEERER, M. Cognitive theory. In G.

Lindzey (Ed.), *Handbook of social psychology*. Cambridge: Addison-Wesley, 1954.

43. STAVRIANOS, B. K. The relation of shape perception to explicit judgments of inclination. *Arch. Psychol., N. Y.*, 1945, No. 296.
44. STOUT, G. F. *Manual of psychology*. (4th ed.) London: Univer. Tutorial Press, 1929.
45. TITCHENER, E. B. *A text-book of psychology*. New York: Macmillan, 1909.
46. TITCHENER, E. B. *Systematic psychology: Prolegomena*. New York: Macmillan, 1929.
47. TOLMAN, E. C., & BRUNSWIK, E. The organism and the causal texture of the environment. *Psychol. Rev.*, 1933, **42**, 43–77.
48. WERNER, H., & WAPNER, S. Toward a general theory of perception. *Psychol. Rev.*, 1952, **59**, 324–338.
49. WOODWORTH, R. S. A revision of imageless thought. *Psychol. Rev.* 1915, **22**, 1–27.

(Received November 27, 1957)

Psychological Review
Vol. 65, No. 6, 1958

A CONCEPT-FORMATION APPROACH TO ATTITUDE ACQUISITION

RAMON J. RHINE

System Development Corporation

The purpose of this paper is to attempt a theoretical formulation of attitude development from a concept-formation point of view. Mediating responses have been employed by Osgood (21) to explain concept formation, and a mediating or implicit response has also been used as a main theoretical construct in Doob's (8) outline of attitude theory. To this extent, there is already an established theoretical link between concepts and attitudes.

Doob calls attitude "an implicit drive producing response considered socially significant in the individual's society" (8, p. 136). This viewpoint has been criticized by Chein for a number of reasons, including the fact that it does not clearly indicate the evaluative nature of attitudes. Chein would rather call attitude a "disposition to evaluate certain objects, actions and situations in certain ways" (3, p. 177). Although many researchers in the field of attitudes might concur with Chein on this last point, a single meaning of attitude upon which there is close agreement is not available. Nelson's (20) review of the literature disclosed 23 more or less different definitions of attitude, and more recent statements could expand the list even further. No one definition seems clearly superior solely on logical grounds; if it were otherwise, there would not be so many alternatives.

The various definitions name constructs, and presumably some constructs have more scientific value than others. The psychologist, seeking a guide for his research among many alternatives, looks for a construct with heuristic and predictive value, particularly a construct which leads to informative research. Insofar as attitude change is concerned, Doob's type of approach has stimulated considerable research. But in the area of attitude development, very little carefully controlled experimentation has been done. Besides the research of Eisman (9), there is little experimentation available on attitude acquisition, although studies such as those by Horowitz (13) and by Clark and Clark (4) provide information about attitude growth. If it is possible to explain attitude learning in terms of concept formation, then attitude development is opened to controlled experimentation through concept-formation methods. A concept-formation approach to attitude learning also enables any systematic viewpoint which can account for concept formation to account at the same time for attitude formation.

The General Meaning of an Attitude

A concept is sometimes thought of as a psychological mechanism that represents a set of stimulus patterns; that is, a concept is considered a mental principle through which an individual can classify a number of objects in his stimulus world. Thus, redwood, elm, pine, fir, and oak fall into the class of "tall, nonanimal, living things," and *tree* is the name given to this principle. Similarly, the concept "a person who speaks with a drawl and has dark skin, thick lips, and kinky hair" classifies American Negroes for some people. Of course, the concepts learned in real life are not always verbalized into a precise prin-

ciple. In fact, behavior in laboratory studies (19) indicates that a concept can be learned even though *S* is unaware of it and is unable to verbalize the principle on which the concept is based. The same phenomenon probably occurs with attitudes. People often betray by their behavior attitudes which they do not recognize as their own.

On a common-sense level, concepts are developed over a period of time through a series of experiences. The child learns the concept *cow* because his parents and others point to objects in the field or in pictures and call them by that name. He learns that color alone is not the key to cow-ness, but that it is helpful. All black objects are not called cow, but green objects are never called by that name. The child soon learns to discriminate between cows and other objects as he learns that cow-ness is a feature of not one stimulus pattern but of a whole class of patterns.

The child learns about people in much the same manner. He discovers that one dimension of Negro-ness is dark skin, but that a deep suntan does not make one a Negro. He gradually learns that Negro-ness involves other dimensions such as facial characteristics and hair properties. This learning eventually enables him to make fairly accurate discriminations between Negroes and other persons. So far, the child has a concept of a Negro but not an attitude, because an attitude involves an evaluative dimension. Suppose, however, he has some unpleasant personal experiences with Negroes or receives adverse information about them from his parents. Then the child's concept might be based on the dimensions, "dark skin, kinky hair, thick lips, speaks with a drawl, and *bad*." Since an evaluative dimension now appears in the concept, he has acquired an attitude.

This approach to attitudes is not an arbitrary substitute for other meanings of attitude, but is representative of commonly used meanings, as may be seen from the following quotations:

"Most researchers in attitudes agree that one of the functions of attitudes is to integrate social perceptions and experiences. Thus our experiences with our mothers, sisters, girl friends and maiden aunts are integrated . . . into an attitude toward women" (16, p. 292). ". . . attitude [is] a more or less permanently enduring state of readiness of mental organization which predisposes an individual to react in a characteristic way to any object or situation with which it is related" (1, p. 13). "The attitude is a way of conceiving an object; it is the mental counterpart of an object" (10, p. 11). ". . . the *meaning* of a concept is its location in a space defined by some number of factors or dimensions, and *attitude* toward a concept is its projection onto one of these dimensions defined as 'evaluative' " (22, p. 42). "An attitude, roughly, is a residuum of experience, by which further activity is conditioned and controlled . . . an inner mental organization takes place which predisposes the person to a certain type of activity towards objects, persons, and situations" (17, p. 238).

The thread which runs through these quotations—"experiences integrated into an attitude," "mental organization," "mental counterpart," "a way of conceiving"—is that an attitude is a kind of mental organization that is built through many experiences. In a sense, as a result of varied contacts with a class of objects, a concentrated representation of a set of stimuli is left within the person, which is the essence of what is generally meant by a concept.

AN EXPLANATION OF ATTITUDE

If an attitude is taken to be a concept with an evaluative dimension, its mean-

ing may be derived from an explanation of concept formation. Consequently, any theory which can explain concept formation can also help to explain attitude development. One of several possible explanations of concept formation is provided by S–R Theory.

Borrowing from Osgood (21), a concept may be defined as the associations between a common response (often verbal) and a set of stimuli. These stimuli frequently comprise a class of phenomena which display certain common characteristics. The common characteristic of the set of phenomena may be the identical elements with which Hull (14) worked, such as a common shape embedded in each of several different Chinese characters. Or, as Smoke (30) has demonstrated, it may be common perceptual relations when, for instance, *S*s view a series of different figures and classify together all those having perpendicular lines in them. Although the stimuli mentioned in the definition of a concept often fall into a class, Osgood suggests that the only essential condition for concept formation is the associations between a common response and a variety of stimuli. There are no obvious stimulus characteristics common to hour-glass, ruler and mental test, all of which are *measuring instruments;* or to file cabinet, typewriter, and desk, all of which are *office equipment*. These items have in common the overt response of naming them, and, of greater theoretical importance, a common mediating process.

The mediating response, Hull's pure stimulus act, can be any fraction of a total response pattern. Partly as a result of the organism's capacity to discriminate, the mediating response will tend to become as fractionated as possible without destroying its cue function.

> The greater the discriminatory capacity of an organism, the more reduced and implicit can become the 'detachable' reactions finally included in the stable mediation process. The higher the organism in the evolutionary scale, the finer the discriminations it can usually make and the less gross its representing processes. Similarly, the more mature and intelligent the human individual, the less overt his symbolic processes. The hosts of fine discriminations that characterize language behavior are Nature's farthest step in this direction (21, p. 398).

Of all possible human mediators, probably the most significant are verbal mediators. Research by Cofer and Foley and associates (5, 6, 7, 12), Riess (28, 29), and others demonstrates the significance for language behavior of mediating responses. Other investigations by Reed (23, 24, 25), Kendler and Karasik (15), and by Goss and associates (2, 11) show the importance of verbal mediators in concept formation. Studies by Eisman (9), Rhine (26, 27), and Staats and Staats (31) show how verbal mediators enter into attitudes.

The general model for a simple, first-order concept based on either verbal or nonverbal mediators is illustrated in Part A of Fig. 1. Many stimuli are conditioned to a common mediating response. By virtue of the common mediator, these stimuli become organized into one system. It is this system of associations between the stimuli and the common mediating process which is the concept. For the concept *gray*, the stimuli of Part A of Fig. 1 would be various acromatic shades all of which arouse the same mediating response. This response provides a stimulus generally conditioned in adults to the overt, verbal label *gray*.

A more complex or second-order concept is illustrated in Part B of Fig. 1. Each set of stimuli with their associated mediators (r_1's) are first-order concepts. In the second-order concept, the stimuli produced by the first-order mediators are themselves associated with another common mediator. One set of first-

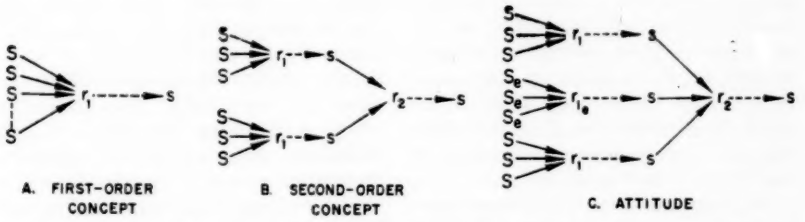


FIG. 1. A stimulus-response explanation of concepts and attitude. S_e = evaluative stimuli; r_1 = a first-order mediator; r_{1_e} = a first-order evaluative mediator; r_2 = a second-order mediator; s = the stimulus produced by a mediator.

order stimuli in Part B of Fig. 1 might be different skin shades leading to the mediator representing *dark skin;* the second set of first-order stimuli might be various lip thicknesses which are associated with the mediator for *thick lips;* and each of the stimuli from these mediating responses may be associated with the mediator for *Negro* (r_2). This illustrates a second-order concept, but there is no attitude as yet because no evaluation is involved.

There is an attitude when the mediator of at least one of the first-order concepts is an evaluative reaction. Thus, attitudes are equivalent to that special class of concepts which is distinguished by the inclusion of an evaluative dimension. Part C of Fig. 1 is a simplified illustration of an attitude. Suppose, as in the example of a second-order concept, that one r_1 of this figure is the mediator for *thick lips,* that the second r_1 represents *dark skin,* and that r_2 is the mediator for *Negro.* Suppose also that the stimuli (S_e) of the evaluative dimension are *dirty, stupid,* and *rude* and that r_{1_e}, the evaluative reaction, is *bad.* Now the stimuli associated with Negro are *dark skin, thick lips,* and *bad.* The inclusion of an evaluative dimension identifies Part C of Fig. 1 as an attitude.

The mediating response produces a stimulus which may then become conditioned to other mediating or instrumental reactions. Part A of Fig. 2 shows some of the major associations possible between the attitude and these other mediating responses. It indicates how instrumental responses may depend upon a chain of associations involving two major types of mediators, namely, affective and verbal. Part A of Fig. 2 is not meant to imply that in any given instance all the illustrated associations between the attitude and verbal or affec-

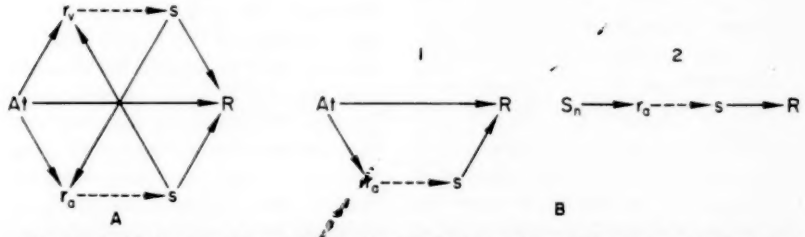


FIG. 2. A: Major associations between the attitude (At = the attitude as shown in Part A of Fig. 1), and verbal (r_v) and affective (r_a) mediators. B: A stimulus-response explanation of prejudice through displaced aggression.

tive mediators will be formed. Instead, it indicates that one or more of the associations may be learned by a given individual. For instance, as is shown in Part B-1 of Fig. 2, only some of the relations between the attitude, affect, and the instrumental response may be learned in an individual case.

One implication of Fig. 2 is particularly interesting. A reaction conditioned to the attitude may be aroused by a stimulus which is associated with affect but not with the attitude. This situation suggests an explanation for prejudiced responses through displaced aggression. Suppose an individual has a negative attitude towards Negroes. Suppose further that the affect of Part B of Fig. 2 is the mediator for *anger* and the instrumental response is aggression toward Negroes. Assume also, as Part B-1 of Fig. 2 indicates, that the attitude leads to the simultaneous arousal of anger and of aggression against Negroes. Eventually, through conditioning, anger alone can lead to aggression. Now, as indicated by Part B-2 of Fig. 2, any stimulus (S_n) which arouses anger will also have a tendency to evoke aggression towards Negroes, depending upon the degree to which this stimulus is supported by other stimuli. As a result, there is a tendency to displace aggression from S_n, the real source of anger, to Negroes.

Other specific predictions follow from the general relations shown in Part A of Fig. 2. The relationship between verbal mediating responses and affect suggests one reason why attitudes are commonly accompanied by affective reactions. If a given verbal mediator, through past experience, has become associated with affect, then the arousal of this mediator by an attitude will also lead to an affective response: the attitude leads to the verbal mediator and the verbal mediator is associated with affect. Suppose, for instance, that an attitude supplies the conditioned stimulus which evokes the verbal mediator for *green vomit*. Then, insofar as this mediator evokes an emotional reaction, the attitude will be accompanied by affect. This particular verbal mediator was used as an example because in some cases it will make the illustration more vivid by actually arousing an emotional reaction in the reader.

There is probably a more important reason why attitudes are commonly linked to affect. It is quite often true that the experiences through which the attitude is developed occur in a charged atmosphere. In this case, the mediating response of the attitude is continuously aroused in conjunction with an emotional reaction, and the stimulus produced by the mediating response becomes a conditioned stimulus capable of evoking affect. As a result, the expression of this attitude is accompanied by an emotional response.

A Method for Studying Attitude Development

One of the main values of the concept-formation approach to attitude is that it suggests a simple laboratory method for studying attitude development. If an attitude is a kind of concept, then its acquisition may be investigated by the methods of concept formation. Such a method, depending on an evaluative dimension in the concept, has been employed by the writer. In order to construct an evaluative dimension, 100 *S*s were asked to rate a large number of descriptive traits in terms of their desirability in a person. Some example traits are: ambitious, boring, calm, intelligent, obedient, and vain. All traits showing less than 90% agreement as to their desirability were discarded. The remaining traits can be employed to study the development of an attitude and to measure its strength and resistance to change. To do this, a

group of *Ss* is told that anthropologists, missionaries and physicians have visited a group of people about which little is known, and that all the visitors agree on certain characteristics of this group of people. When these instructions are concluded, *Ss* are shown a number of traits, one by one, and are asked to predict whether each trait is or is not characteristic of the people. After each prediction they are told whether or not the word is indeed characteristic. For example, to develop a positive attitude, *E* would say "characteristic" after presenting each trait previously rated as desirable and "not characteristic" for words previously rated undesirable.

If *S* has learned the positive attitude, which might be labeled "pro-ness," he would be expected to respond accordingly. Hence, when he has completed the first list of traits, *S* is asked to continue responding in the previous manner to a second list of words without being told which traits are characteristic or not characteristic. Responses under this condition are taken as a measure of attitude strength. It is assumed that a strongly acquired, positive attitude will lead to a high proportion of positively rated traits being called "characteristic" and to most negatively rated traits being called "not characteristic."

Finally, resistance to attitude change is measured by using a third list of traits with *E* again saying "characteristic" or "not characteristic" after each prediction. But this time *E*'s responses are reversed. For example, if *S* has previously acquired a positive attitude, change may be accomplished by calling "not characteristic" all positive traits in the third list and "characteristic" all negative traits.

This method is derived from the concept-formation approach to attitudes. The meaning of the many traits seen in a single session varies considerably, as can be observed from the examples given above. Although the traits are not synonyms, they do exhibit one common aspect, the evaluative element. The *Ss* are able to respond correctly when this evaluative element is consistently reinforced by *E* because the traits are stimuli which are capable of arousing a common, evaluative mediating response. The mediating process, in turn, determines *S*'s further predictions of "characteristic" or "not characteristic."

The stimulus function of mediating responses in attitude development is demonstrated by two experiments which also illustrate the mediating response approach as applied through the concept-attitude method. A negative attitude was developed in both investigations. In one study (27), consistency of reinforcement was defined as the sum of the number of positive traits called "not characteristic" by *E* and the number of negative traits called "characteristic," divided by the total number of traits used during attitude development. Using five levels of consistency, it was shown that both attitude development and strength increase as a function of consistency of reinforcement, as would be predicted from the approach to attitude development based on mediating responses. The results for attitude change also suggest that attitudes exhibit properties of mediating responses. Research on acquired distinctiveness of cues (18) indicates that strong habits reverse more easily than weak ones when the cues arousing them have become distinct through learning. The distinctiveness of the stimulus dimension is believed to be related to the degree to which the stimuli are conditioned to a mediating process. The evaluative element of the stimulus traits should be most distinct when reinforcement is fully consistent; consequently, attitude change should be easiest under this con-

dition. The *Ss* receiving the greatest consistency of reinforcement did in fact show least resistance to change.

A second experiment (26) illustrating the concept-attitude method investigated the effect on attitude development of peer responses. The traits were used with 100% and 84% consistency of reinforcement to develop a negative attitude. Some *Ss* made their predictions after first hearing the responses of three fellow students who were *E*'s confederates, and other *Ss* made their predictions in private. The confederates' responses prior to *S*'s predictions were always or almost always in contradiction with the statement *E* made after each prediction. Thus, when the confederates said a trait was characteristic, it was pretty certain that *E* would say the trait was not characteristic. The *Ss* who heard the confederates' responses learned the attitude with greater ease than those who responded in private. Apparently, peer responses provided cues which were an aid to *S* in attaining the attitude. This seemed to occur mainly with high consistency of reinforcement. With less than full consistency of reinforcement, peer responses were predictive of *E*'s behavior for a majority of the traits, but not all of them. When this ambiguity is introduced, cues from peer responses do not affect attitude development at a statistically significant level, although there is a slight trend in this direction.

These results may be explained by considering the effect of peer responses upon the arousal of the common, evaluative mediating response. With 100% consistency of reinforcement, a negative mediating reaction is aroused by a trait just prior to reinforcement and in conjunction with peer responses of "characteristic." Similarly, a positive mediating reaction is aroused in conjunction with peer responses of "not characteristic." In time, as a result of conditioning, the peer responses can be expected to help cue the appropriate positive or negative mediating response. With 84% consistency of reinforcement, the trend of conditioning is the same, but a minority of trials tend to establish competing, mediating responses: the same peer reactions are sometimes associated with positive mediating responses and sometimes with negative. Under these conditions, peer responses are a less stable and less predictive aspect of the stimulus environment. This would account for the statistically significant effect from peer responses with high consistency of reinforcement, which is diminished with lesser consistency.

Staats and Staats (31) have also studied attitudes using an approach similar to that employed in the preceding two studies. The associated given names, Tom or Bill, and nationalities, Dutch or Swedish, with positive or negative evaluative words. Subsequent ratings indicate that the given names and nationalities took on the same evaluative flavor as the words with which they were associated. The researchers explain their results by pointing to the common, evaluative mediating response made to the words which are paired with the nationalities and names. It is assumed that through conditioning the names (or nationalities) would also lead to the mediating response aroused by the words with which they were paired. This was reflected when the names (or nationalities) were rated on the evaluative scale.

The studies derived from the concept theory of attitudes illustrate the possibility of bringing attitude development under laboratory scrutiny. Despite the generally recognized significance of attitude development, as distinguished from attitude change, the literature reveals relatively little laboratory evidence bearing upon its nature. It is hoped that the concept theory of attitudes and the

method it implies will help provide a means through which attitude development will be more accessible to experimental investigations.

SUMMARY

A theory of attitude development based upon concept formation was discussed, and similarities between this view and earlier meanings of attitude were pointed out. An attitude was defined as a concept with an evaluative dimension, and the mediating response was employed to explain attitude learning. A method for inducing an attitude in the laboratory was described along with illustrative studies employing this method.

REFERENCES

1. CANTRIL, H. Attitudes in the making. *Understanding the child*, 1934, **4**, 13–14, 18.
2. CAREY, J. E., & GOSS, A. E. The role of verbal labeling in the conceptual sorting behavior of children. *J. genet. Psychol.*, 1957, **90**, 69–74.
3. CHEIN, I. Behavior theory and the behavior of attitudes: Some critical comments. *Psychol. Rev.*, 1948, **55**, 175–188.
4. CLARK, K. B., & CLARK, MAMIE P. Racial identification and preference in Negro children. In G. E. Swanson, T. M. Newcomb, & E. L. Hartley (Eds.), *Readings in social psychology*. New York: Holt, 1952.
5. COFER, C. N., & FOLEY, J. P. Mediated generalization and the interpretation of verbal behavior: I. Prolegomena. *Psychol. Rev.*, 1942, **49**, 513–540.
6. COFER, C. N., & FOLEY, J. P. Mediated generalization and the interpretation of verbal behavior: II. Experimental study of certain homophone and synonym gradients. *J. exp. Psychol.*, 1943, **32**, 168–175.
7. COFER, C. N., JANIS, MARJORIE E., & ROWELL, MARY M. Mediated generalization and the interpretation of verbal behavior: III. Experimental study of antonym gradients. *J. exp. Psychol.*, 1943, **32**, 266–269.
8. DOOB, L. W. The behavior of attitudes. *Psychol. Rev.*, 1947, **54**, 135–156.
9. EISMAN, BERNICE S. Attitude formation: The development of a color preference response through mediated generalization. *J. abnorm. soc. Psychol.*, 1955, **50**, 321–326.
10. FARIS, E. The concept of social attitudes. In K. Young (Ed.), *Social attitudes*. New York: Holt, 1931.
11. FENN, J. D., & GOSS, A. E. The role of mediating verbal responses in the conceptual sorting behavior of normals and schizophrenics. *J. genet. Psychol.*, 1957, **90**, 59–67.
12. FOLEY, J. P., JR., & MATHEWS, M. A. Mediated generalization and the interpretation of verbal behavior: IV. An experimental study of the development of interlinguistic synonym gradients. *J. exp. Psychol.*, 1943, **33**, 188–200.
13. HOROWITZ, E. L. The development of attitude toward the Negro. *Arch. Psychol.*, 1936, No. 194.
14. HULL, C. L. Quantitative aspects of the evolution of concepts. *Psychol. Monogr.*, 1920, **28**, No. 1 (Whole No. 123).
15. KENDLER, H. H., & KARASIK, A. D. Concept-formation as a function of competition between response produced cues. *J. exp. Psychol.*, 1958, **55**, 278–283.
16. KRECH, D. Attitudes and learning: A methodological note. *Psychol. Rev.*, 1946, **53**, 290–293.
17. KRUEGER, E. T., & RECKLESS, W. C. *Social psychology*. New York: Longmans, Green, 1931.
18. LAWRENCE, D. H. Acquired distinctiveness of cues: II. Selective association in a constant stimulus situation. *J. exp. Psychol.*, 1950, **40**, 175–188.
19. LEEPER, R. Cognitive processes. In S. S. Stevens (Ed.), *Handbook of experimental psychology*. New York: Wiley, 1951.
20. NELSON, E. Attitudes: I. Their nature and development. *J. genet. Psychol.*, 1939, **21**, 367–399.
21. OSGOOD, C. E. *Method and theory in experimental psychology*. New York: Oxford Univer. Press, 1953.
22. OSGOOD, C. E., & TANNENBAUM, P. H. The principle of congruity in the prediction of attitude change. *Psychol. Rev.*, 1955, **62**, 42–55.
23. REED, H. B. Factors influencing the learning and retention of concepts: I. The influence of set. *J. exp. Psychol.*, 1946, **36**, 71–87.
24. REED, H. B. The learning and retention of concepts: II. The influence of length

of series. III. The origin of concepts. *J. exp. Psychol.*, 1946, **36**, 166–179.

25. REED, H. B. The learning and retention of concepts: IV. The influence of complexity of the stimuli. *J. exp. Psychol.*, 1946, **36**, 252–261.
26. RHINE, R. J. The effect of peer group influence upon concept-attitude development and change. *J. soc. Psychol.*, in press.
27. RHINE, R. J., & SILUN, B. A. Acquisition and change of a concept attitude as a function of consistency of reinforcement. *J. exp. Psychol.*, 1958, **55**, 524–529.
28. RIESS, B. F. Semantic conditioning involving the GSR. *J. exp. Psychol.*, 1940, **26**, 238–240.
29. RIESS, B. F. Genetic changes in semantic conditioning. *J. exp. Psychol.*, 1946, **36**, 143–152.
30. SMOKE, K. L. An objective study of concept formation. *Psychol. Monogr.*, 1932, **42**, No. 4 (Whole No. 191).
31. STAATS, A. W., & STAATS, CAROLYN K. Attitudes established by classical conditioning. *J. abnorm. soc. Psychol.*, 1958, **57**, 37–40.

(Received January 28, 1957)

Psychological Review
Vol. 65, No. 6, 1958

SYMPTOMS AND SYMPTOM SUBSTITUTION

AUBREY J. YATES

University of New England, Australia

In recent years there has been a number of attempts to derive rational methods of symptomatic treatment of the behavioral disorders, based mainly on learning theory (10, 12, 13, 15, 18, 19) and information theory (2). Nevertheless, symptomatic treatment has not been favorably considered by most clinical psychologists, and the failure to appréciate its possibilities is perhaps best shown by the almost total neglect of Dunlap's classic work (3) on habit-formation and the remedial treatment of undesirable habits. The object of this paper is to point out some misconceptions on which objections to symptomatic treatment are based, and to show that such treatment can in fact be firmly founded on modern learning theory.

The argument that symptomatic treatment is a waste of time has had as its strongest proponent the psychoanalytic school, which has insisted that symptoms are but the surface indicators of underlying conflicts, anxieties, etc. This argument has been accepted by most "dynamic" psychologists, who concluded that removing the symptom without also effectively treating the anxiety or conflict underlying it would lead to symptom substitution. For example, even if tics could be treated directly and extinguished, the patient would quickly develop either new tics or some other form of symptomatic response. Even orthodox psychiatrists who have little patience with Freudian psychodynamics have accepted this point of view. Thus Kanner writes that "symptomatic therapy which does not care what the complaint is a 'symptom' of is rarely successful and leads to unwarranted pessimism" (9, p. 244). Mowrer has summed up the position neatly and abusively:

> . . . the behavioral manifestations which we now call "symptoms" are not the essence of neurosis and . . . the modes of treatment that are aimed at their direct alleviation are as ill-considered theoretically as they are futile practically (14, p. 620).

This point of view has become so widely accepted that until recently almost no symptomatic treatment was carried out, except in the educational field of remedial teaching and speech therapy. However, the distinction between a "fundamental" underlying anxiety and a "superficial" surface symptom is open to a number of objections.

1. The term "symptom" has been employed very loosely in psychology. In general medicine a clear distinction is made "between symptoms, that is disorders described by the patient, and physical signs or the deviations from the normal revealed by examination" (7, p. 1). In other words, a symptom is a subjectively experienced abnormality, a sign is an objective indication of abnormality. In many cases the symptom may, of course, also be a sign.

Mowrer, having accepted, as we have seen, Freud's conclusion with regard to the meaning and function of symptoms, was considerably embarrassed by his own empirical finding that "symptomatic" treatment of enuresis was not only 100% successful with regard to the symptoms, but was not followed by symptom substitution in a single case! Instead, however, of rejecting Freud's hypothesis, Mowrer took the extraordinary step of denying that enuresis was a symptom in any of the cases he treated. He distinguished between habits

which were also symptoms, and habits which were not. Thus,

> "symptoms" differ from ordinary "habits" primarily in that the former are motivated by and are perpetuated because they lessen the drive of anxiety, whereas "normal" habits are motivated by and are perpetuated because they lessen other drives, such as hunger, thirst, cold, fatigue, sex, fear, etc. (14, p. 546).

Now the above distinction is clearly a meaningful and possibly a valid one. As far as the author is aware, however, Mowrer has not presented any evidence that the distinction can be sustained in the form in which he has put it, and his own experimental results seem strongly to contraindicate the validity of any such distinction. Mowrer's acrobatics in this regard are as good an example as any of an a priori clinical bias being allowed to outweigh cogent experimental evidence.[1]

It is clear that, as used by Freud (6), Mowrer (14), and other "dynamic" psychologists, the symptom is regarded as a response to some hidden, basic conflict or anxiety. It will be suggested that this "vertical," dualistic approach in unnecessary and should be replaced by a "horizontal," monistic approach, as described below.

2. The "dynamic" approach ignores the distinction between neuroticism and neurosis (4). Neuroticism may be conceptualized as an innate predisposition to develop a neurosis under certain specifiable conditions. This conceptualization is at least as plausible as the alternative outlined above. But, if such a predisposition exists, then it follows that a neurosis *is* symyptoms and nothing else, i.e., that a particular neurosis consists of a particular set of learned responses; and that treatment on psychological grounds can only be symptomatic, since treatment of the predisposition must ultimately be by genetic or chemical means.

3. Finally, it should be noted that belief in symptom substitution seems to be based largely on clinical experience. Considering the significant role such a distinction has played in clinical psychology, experimental demonstration of its existence is singularly lacking. We conclude, therefore, that the reasons generally given for rejecting symptomatic treatment in favor of "dynamic" treatment are not soundly based. Nevertheless, the definition of a neurosis as a system of learned responses is not in itself incompatible with the notion of symptom substitution. We must now turn to the question whether there are any theoretical reasons to suppose that symptom substitution would take place, if symptomatic treatment were to be undertaken. It will be maintained that learning theory suggests both that symptomatic treatment is a rational procedure and that symptom substitution would not be expected except under certain specifiable conditions.

This may perhaps be most easily shown by reference to some recent work on the symptomatic treatment of tics (cf. 19 for details). A model was constructed to account for the genesis of some tics in terms of two-factor learning theory. It was hypothesized that the tic is a conditioned avoidance response to anxiety, the latter being a learned response (the conditioned form of the original fear response). A method of treatment was derived in terms of the Hullian concepts of I_R and ${}_sI_R$, making use of massed practice.[2] With regard to this theory, the follow-

[1] Mowrer admits that it is impossible to "know from the incontinence alone that it is a symptom rather than simply a reflection of pedagogical inadequacy" (14, p. 414). Presumably, therefore, decision as to whether the incontinence is a symptom or a habit can be determined only by carrying out "symptomatic" treatment and seeing what happens.

[2] In this study (19) it was found convenient to use the concepts of I_R and ${}_sI_R$ in deriving a method of treatment. This aspect could also, however, have been conceptualized in terms of two-factor learning theory, as Mowrer has shown in connection with studies in the field of general motor behavior (14, p. 169, Footnote 4).

ing points are specifically relevant to this discussion:

a. Both the anxiety and the tic are learned responses. Now it would be a logical error to suppose that the fact that the tic is a response *to* the anxiety necessarily means that the anxiety must therefore be more fundamental or that it must receive prior treatment. It seems more reasonable to regard the situation simply as one in which two sets of responses (anxiety and the response to anxiety) are learned over time. This may be termed the "horizontal" approach, as opposed to the dualistic "vertical" approach rejected above.

b. From this point of view it does not much matter which aspect of behavior (anxiety or tic) is treated first. The fact is, however, that in our present state of knowledge it is easier to treat the tic than the anxiety. The former is more readily manipulated and measured, and, since it usually involves motor behavior, is easily dealt with in relation to the concepts of learning theory. It turns out, however, that in treating the symptom we are also treating the anxiety. For suppose the symptom is destroyed; then the anxiety, instead of being reduced by it, will persist. But since in fact no traumatic event occurs if the anxiety is allowed to persist, the latter, being itself a learned response, will begin to extinguish. This is what in fact seems to happen, though the principle of partial irreversibility of traumatic anxiety (17), if valid, suggests that extinction of the anxiety would never be complete.[3]

This formulation is, of course, derived directly from Mowrer's two-factor theory of learning. That removal of the symptom will affect the learned anxiety is hinted at by Mowrer, when he explains why a symptom

> is at one and the same time both self-perpetuating and self-defeating. It is self-perpetuating because it is reinforced by the satisfaction provided through the resultant anxiety reduction; and it is self-destructive in that *it prevents the individual from experiencing the full force of his anxiety and being modified by it in such a direction as to eliminate the occasion for the anxiety* (14, p. 535, Footnote 3; italics not in original).

Supposing, therefore, both the symptom and the anxiety to be alleviated, we would be left with a basically neurotic person without a current behavior disorder. But, in terms of learning theory, there would be no reason to suppose that this person would develop new anxieties or symptoms unless put into a new traumatic situation. This would, of course, involve knowledge of what situations would be likely to be traumatic for a particular patient.[4]

Such empirical evidence as there is supports the position outlined above. Symptom substitution has not been found in those instances where a single patient has been subjected to intensive investigation and symptomatic treatment (e.g., 8, 12, 19); nor in those few instances where large-scale follow-up has been carried out on groups of subjects. For example, two recent investigations (1, 11) of the results of symptomatic (*pace* Mowrer) treatment of enuresis indicate 70%–80% success, and a failure to find symptom substitution over periods up to two years. Mowrer himself (13) reported 100% success. The critical point seems to be that we are faced in such cases with a vicious circle (as Mowrer has indeed pointed out): the tic, for example, is a response to

[3] The nature of traumatic avoidance learning is a very complex problem, which has been greatly oversimplified here. The reader is referred to recent papers by Solomon and Brush (16) and by Solomon and Wynne (17) for comprehensive discussions of the current position.

[4] In the case of the patient treated by the author, for example, any situation involving anaesthesia (such as dental or medical operations) would be potentially traumatic.

anxiety, but performance of the tic increases the general level of drive (irritability, annoyance, etc.), which increases the rate of responding, and so on. The important factor seems to be the breaking of this vicious circle; it does not much matter whether this is accomplished by treating the anxiety or the symptom, since both react upon each other. Thus, in the shadowing method described by Cherry and Sayers (2) for the treatment of stammering, the mere fact of demonstrating to the patient that he can speak normally (even though under special conditions and before treatment has started) usually has a very striking effect on the patient's general well-being. In many instances it seems that the symptom itself generates a good deal of anxiety, which can be alleviated by a direct attack on the symptom.

The seriousness of the present situation is clearly demonstrated by Eysenck's recent contention (5, p. 271) that, in spite of the experimental validation of symptomatic treatment of enuresis, this technique is not used in any child guidance clinic in Great Britain. It is obvious that a reorientation is highly desirable, in which the "vertical" approach is abandoned, the use of the term "symptom" dropped altogether, and the patient considered as an individual who has developed a series of learned responses to certain situations. Clinical psychologists may then perhaps begin to apply that large body of knowledge and theory to be found in general psychology in which they are specially trained, and apply the principles of behavior to the abnormal field as well as to the normal.

REFERENCES

1. BALLER, W., & SCHALOCK, H. Conditioned response treatment of enuresis. *Except. Child*, 1956, **22**, 233–236.
2. CHERRY, C., & SAYERS, B. McA. Experiments upon the total inhibition of stammering by external control and some clinical results. *J. psychosom. Res.*, 1956, **1**, 233–246.
3. DUNLAP, K. *Habits. Their making and unmaking*. New York: Liveright, 1932.
4. EYSENCK, H. J. *The scientific study of personality*. London: Routledge & Kegan Paul, 1952.
5. EYSENCK, H. J. *The dynamics of anxiety and hysteria*. London: Routledge & Kegan Paul, 1957.
6. FREUD, S. *The problem of anxiety*. New York: Norton, 1936.
7. HOLMES, G. *Introduction to clinical neurology*. Edinburgh: Livingstone, 1946.
8. JONES, H. G. The application of conditioning and learning techniques to the treatment of a psychiatric patient. *J. abnorm. soc. Psychol.*, 1956, **52**, 414–419.
9. KANNER, L. *Child psychiatry*. Springfield, Ill.: Charles C Thomas, 1935.
10. LIVERSEDGE, L. A., & SYLVESTER, J. D. Conditioning techniques in the treatment of writer's cramp. *Lancet*, 1955, **2**, 1147–1149.
11. MARTIN, B., & KUBLY, D. Results of treatment of enuresis by a conditioned response method. *J. consult. Psychol.*, 1955, **19**, 71–73.
12. MEYER, V. The treatment of two phobic patients on the basis of learning principles. *J. abnorm. soc. Psychol.*, 1957, **55**, 261–266.
13. MOWRER, O. H. Enuresis: A method for its study and treatment. *Amer. J. Orthopsychiat.*, 1938, **8**, 436–459.
14. MOWRER, O. H. *Learning theory and personality dynamics*. New York: Ronald Press, 1950.
15. RAYMOND, M. J. Case of fetishism treated by aversion therapy. *Brit. med. J.*, 1956, **2**, 854–857.
16. SOLOMON, R. L., & BRUSH, E. S. Experimentally derived conceptions of anxiety and aversion. In M. R. Jones (Ed.), *Nebraska symposium on motivation*. Lincoln: Univer. Nebraska Press, 1956. Pp. 212–305.
17. SOLOMON, R. L., & WYNNE, L. C. Traumatic avoidance learning: The principles of anxiety conservation and partial irreversibility. *Psychol. Rev.*, 1954, **61**, 353–385.
18. WOLPE, J. Experimental neuroses as learned behavior. *Brit. J. Psychol.*, 1952, **43**, 243–268.
19. YATES, A. J. The application of learning theory to the treatment of tics. *J. abnorm. soc. Psychol.*, 1958, **56**, 175–182.

(Received January 30, 1958)

Psychological Review
Vol. 65, No. 6, 1958

TRANSFER OF TRAINING AND ITS RELATION TO PERCEPTUAL LEARNING AND RECOGNITION [1]

JAMES M. VANDERPLAS

Washington University

It is the purpose of this paper to bring together several current concepts arising from the study of transfer of training and to consider their implications for the study of perceptual learning and recognition. A number of studies have indicated an increasing emphasis on relations between these two areas (1, 2, 3, 12, 13, 21, 22, 27, 38), and several theoretical formulations have been advanced to account for certain phenomena in perceptual learning and recognition in terms of existing principles of transfer (12, 21, 26, 37). In several instances, however, the reverse of this latter kind of account has been advanced; that is, certain phenomena in transfer of training have been held to support theoretical formulations grounded upon assumptions involving processes of perceptual learning (3, 15, 16, 17, 20).

In the first kind of view, recognition or discrimination tasks have been employed to provide evidence for hypotheses concerning changes in stimulus-response relations which take place during learning. This view is illustrated nicely by the study by Arnoult (2). Four groups of subjects learned to associate verbal labels with nonsense forms. In one group the labels were nonsense syllables; in a second group the labels were girls' names; in a third group the labels were descriptive names given the forms by an independent group; in the fourth group the labels were names invented by the subjects themselves. Following this labeling practice, the subjects were given a recognition test, in which they were required to select from a group of forms those for which they had learned the labels. Recognition was found to increase as a function of the degree to which the responses in the paired-associates task (learning labels) reflected associations made to the forms. The implication from this kind of study is that recognition, as a perceptual task, is dependent (at least in part) upon the degree to which responses, in this case labeling responses, transfer from the first task to the task of recognition. Clearly, then, from this point of view, the process of recognition is intimately related to what may be regarded as stimulus-response relations, consistent with long-standing associationistic theories.

In the second kind of view, the converse of the above statement is usually made; transfer comes about as a function of underlying perceptual processes. This view finds support in studies of the kind made by Gagné and Baker (15). In this study, subjects were given preliminary practice in associating a different letter to each of four different lights. Following this practice the subjects engaged in a second task in which the same lights were used as stimuli as were used in the first task, but the responses were changed to require the subjects to manipulate a different switch when each of the four lights appeared. The scores (time and errors) were found to vary in

[1] This research was supported in part by the United States Air Force under Contract No. AF 41 (657)—47, monitored by the Operator Laboratory, Air Force Personnel and Training Research Center, Lackland Air Force Base, San Antonio, Texas. Permission is granted for reproduction, translation, publication, use, and disposal in whole or in part by or for the United States Government.

a way which was related to the amount of practice in the first task. The rate at which the subjects learned to respond by manipulating the correct switch increased as a function of practice in associating labels, and significant differences in errors were found as a function of the amount of first-task practice. These results were interpreted by the investigators as supporting the view that practice in labeling brought about a reduction in generalization in responses among the various intratask stimuli. In their view, the practice increased the degree to which the stimuli were differentiated from each other. A similar point of view, although based on a somewhat different mechanism, is contained in the well known hypothesis of Miller and Dollard (33) of acquired distinctiveness of cues.

Although these two kinds of views have not always been stated explicitly, they appear in a variety of theoretical formulations (to be examined later in this paper) and in a number of studies of transfer of training (9, 11, 29, 30), stimulus predifferentiation (1, 3, 6, 15, 16, 20, 38), acquired distinctiveness of cues (21, 33, 39), and in studies of perceptual learning (7, 12, 13, 38). It is evident that these views are closely related. The first view mentioned above implies a close relation between verbal and motor responses, *qua* responses, and responses which are presumed to reflect or to influence perceptual responses. The second view implies that verbal and motor responses may be related to stimulus variables which influence perceptual processes. Thus, we might expect that perceptual learning and recognition are activities which are understandable in terms of transfer of training and, conversely, that transfer of training is dependent upon (or, in the least, involves) processes similar to those encountered in studies of perceptual learning and recognition. However, as obvious as these relations, stated in this broad sense, appear at first, several difficulties arise almost immediately to plague the investigator who attempts to interpret in any clear fashion the results of experiments in these areas.

Taken as a group, the studies cited above tend to support a common conviction among psychologists that transfer is involved in practically all phenomena beyond those of the simplest reflex variety. Conversely, however, they also support an equally common conviction that perception is involved in practically all forms of activity, in one way or another.

But if one examines carefully the frameworks of these convictions, one encounters several difficulties. First of all, the principles of transfer of training themselves do not find unequivocal support in experiments designed to test them. For example, a frequently cited principle of transfer, made most explicit in the formulation of Osgood (36), is that when responses are different in two tasks, transfer will occur from one task to the other in a fashion inversely related to the degree of similarity of the responses in the tasks. Positive transfer will occur when the responses are similar, and zero or negative transfer will occur when the responses are unrelated or antagonistic. But a direct test of this principle, in an experiment by Bugelski and Cadwallader (10), in which responses were varied over a wide range, yielded data contradictory to the principle.

Second, specification of the ways in which responses, *qua* responses, in transfer formulations on the one hand, and responses presumed to reflect recognition on the other hand, are related, is far from clear. One not only finds perceptual responses interpreted as instrumental activity dependent upon inferred responses of an identification type (26), but one also finds instrumental responses

interpreted as resulting from processes involving changes in perception (20). These differences in interpretation of the activities only lead to confounding of the investigator interested in a clear statement of principles.

Third, the variables which are employed to represent the various concepts in these views are often subject to interpretations which support alternative views with almost equal likelihood. In Arnoult's experiment, for example (2), the response of recognition (selection of the correct nonsense form) could be interpreted as resulting either from reduction in generalization or from facilitation of the correct response (*qua* response), brought about directly by way of the intervening identification response that had been made during the practice in labeling. A similar interpretation could be made of the results of the experiment by Gagné (15), cited above. The correct switching response could result either from reduction in generalization (predifferentiation), acquired distinctiveness (33), or from an increase in likelihood of the correct response due to its relation to the response in the first task (9, 30). Thus, although recognition may be interpreted broadly as resulting from one or another of the principles of transfer, the difficulties mentioned here suggest that it is in good order to reexamine some of the hypotheses generated from the various studies.

THE RELATION BETWEEN TRANSFER OF TRAINING AND RECOGNITION

Despite a considerable divergence in point of view and method between studies of transfer and recognition, they involve similar experimental operations.[2] Their similarities may be illustrated by considering the following paradigms.[3]

Recognition

Training or experience is provided by engaging the subject in a task in which he is asked to observe, label, draw, or otherwise respond to a form, a pattern, or other stimulus. Several such stimuli may be used. Following training, he may be asked in a second task to select those stimuli used in the first task from among a group containing both the old and some new stimuli.

This paradigm has been employed in a number of studies designed to test hypotheses about effects of predifferentiation or acquired distinctiveness training upon transfer, in both verbal and motor tasks (1, 2, 3, 9, 12). In a study by Vanderplas and Garvin,[4] for example, training was employed in which subjects were required to learn nonsense labels for a series of nonsense forms. Following this labeling practice, a test of recognition was employed in which the subjects were required to select the forms for which labels were learned when imbedded in a set of forms containing both the old forms and several similar ones. Several conditions were employed, including amount of practice

[2] Difference in point of view concerning similar operations may be illustrated by considering a situation in which a person encounters a woman, approaches her, and says, "Hello, Mary." If the woman were not in fact named Mary, the response might be regarded as a false recognition. But if the woman were one of a group of women and if the person had the task of learning the names of each woman, the response "Hello, Mary" might be regarded as a case of positive transfer, provided that another woman (in a previous situation) had been correctly called Mary by the person.

[3] The experimental controls necessary in this and the following paradigm are not cited here, since they are intended to show similarities. Controls vary with the phenomena under investigation, and serve to distinguish experiments rather than points of view.

[4] A report of this research, entitled "Complexity, Association Value, and Practice as Factors in Recognition Following Paired-Associates Verbal Training," is now in preparation.

and certain physical variations in the forms. The study, however, illustrates the use of the paradigm as a test of the hypotheses mentioned above. As another example, the study by Kurtz and Hovland is of interest: in their study (27), subjects who verbalized the names of common objects were found to recognize them with greater certainty in a second task than a group who did not so verbalize. The results thus supported the hypothesis that the naming response increased the probability of correct recognition. For the present purpose, the study illustrates once again the point of view, mentioned earlier, that recognition may be influenced by the relation that it bears to responses made in the initial task. The paradigm, as described above, has also been employed in studies of concept formation (8) and in the more classical experiments on form and pattern perception (40, Ch. 23). In studies where this paradigm has been employed, it is usually inferred that the response of recognition is dependent upon its relation to responses (most often of an identification type) made during practice on an initial task, and thus closely related to existing principles of transfer of training.

Transfer of Training

Training is provided in which the subject is required to make a verbal or motor response to a set of stimuli, such as lights, tones, words, nonsense syllables, or even forms or patterns. Following this training he is required to perform a second task which may be of one or more of the following types (symbolized in S–R terms, for convenience):

Type SRSR: The subject is asked to respond in the second task as he did in the first, to the same stimuli.
Type SRsR: The subject is asked to respond in the second task as he did in the first, but to stimuli different from those of the first task.
Type SRSr: The subject is asked to respond differently in the second task to the same stimuli used in the first.
Type SRsr: The subject is asked to respond differently in the second task to stimuli different from those used in the first.

In these paradigms, instructions to the subject may include directions to respond as above, or he may be given only general instructions such as those provided in paired-associates training where he is asked to attempt to anticipate each response item in a list.

The paradigms have been extensively employed in studies of predifferentiation, acquired distinctiveness of cues, transfer, and retention. It is often inferred from the experimental results, in studies employing these paradigms, that the response employed in the first task facilitates performance of the second if transfer is demonstrated. For example, in a study by McAllister (30), it was shown that when a verbal response employed in a first task had some degree of "relevance" to a corresponding motor response in a second task, transfer increased. The relevance of the first-task response to the motor response was by way of the denotative character of the verbal response (e.g., "up-left," and the corresponding movement of a lever in the star discrimeter).

When these paradigms are thus considered, in terms of the stimulus-response relations in the two tasks, several points of close correspondence in the points of view mentioned earlier become apparent. First of all, in the recognition paradigm, the subject is asked to respond in the second task (usually by implication) in two ways: (*a*) as he did in the first to the same stimuli, and (*b*) differently to different

stimuli. If he responds correctly with the responses that he learned during first-task training, it is predicted by the transfer theorist that the response of recognition will be facilitated. Conversely, if recognition is found to improve following practice in labeling, say, it is inferred that the response of labeling facilitated recognition. These requirements, implicitly made in the recognition paradigm, are tantamount to imposing, simultaneously, tasks of Type *SRSR* and *SRsr* of the transfer paradigm. Thus, experiments on recognition which implicitly impose these requirements may be regarded as forms of transfer tasks which involve simply differential response. Conversely, transfer experiments which impose similar tasks may support a view that differential responses arise from processes of recognition.

To emphasize the relations between these paradigms, consider also the following.

1. Tasks of Type *SRSR* require retention of a stimulus, a response, or a specific S–R relation from the first task to the second. They also require recognition of the stimulus in order that the correct response can be made.

2. Tasks of Type *SRsR* may require generalization of a response from first-task stimuli to similar stimuli in the second. Failure of recognition or differential discrimination would result in positive transfer.

3. Tasks of Type *SRSr* may require a different response to the same stimuli in the second task. Failure to recognize a stimulus as old could result in positive transfer; i.e., the subject would respond differently, as required. Correct recognition would result in negative transfer, since the subject would respond with the old response, and interference would result.

4. Tasks of Type *SRsr* require differential responses to different stimuli in the two tasks. Recognition should result in just such performance. Zero transfer would be predicted, however, since no old stimuli are present to evoke the recognition response.

To summarize, recognition and transfer may be regarded as directly related, inversely related, or not related at all, depending upon the relations between the stimuli, responses, or both, in the two tasks. In general (but only in general), they may be regarded as related by way of the common requirement of differential response to different stimuli and its relation to activities which reflect recognition. With these points in view, let us examine some current principles of transfer as they relate to the study of recognition.

APPLICABILITY OF PRINCIPLES OF TRANSFER TO THE STUDY OF RECOGNITION

A number of investigators have attempted to account for transfer of training in verbal and motor tasks by application of hypotheses derived from studies of perceptual phenomena, primarily those involving discrimination. At the same time, hypotheses arising out of association theory (31, 32, 37), studies of concept formation (8), and S–R formulations (21) have been invoked to account for data otherwise presumed to reflect perceptual processes. Although they have seldom been advanced in pure form, we may distinguish three divergent points of view on these questions.

First, classical theory regards transfer to be a function of S–R relations, and to be dependent upon similarity relations between stimuli or responses in the two tasks. This view is clearly seen in the transfer and retroaction model of Osgood (36), to which we have already made reference. A second view is seen in the studies of stimulus predifferentiation. Transfer is now regarded as a

function of changes in discriminability of stimuli, either as a result of reduction of generalization gradients (18) or as a result of increased distinctiveness arising from the addition of response-produced cues (21, 33). This view is presented in the well known hypothesis of Miller and Dollard (33), and in the extended formulation of Goss (21). A third view regards transfer as resulting from certain mediational processes, including verbal associations to task stimuli. This view has received emphasis in the recent discussion by Postman, who holds to the point that perceptual learning may be encompassed by association theory, by way of an account which includes verbal response processes (37). To what extent each of these divergent views is relevant to the study of recognition is a question of some concern. We shall next attempt to examine these formulations with this question in mind.

S–R Similarity Relations and Transfer

Osgood, in his treatment of transfer (36), regards three principles to be of primary importance in determining the direction and extent of transfer: (*a*) when responses in the two tasks are (functionally) identical, positive transfer is obtained and increases with increasing similarity of the stimuli; (*b*) when the stimuli in the two tasks are (functionally) identical, with responses varied, negative transfer is obtained and decreases with increasing similarity of the responses; (*c*) when both stimuli and responses are varied, negative transfer is obtained and increases with increasing stimulus similarity.

It is apparent from the foregoing discussion of the paradigms cited that these principles, paraphrased from Osgood's discussion of the model (36, pp. 134–135), are partly principles of recognition. However, some qualifications need to be mentioned. First, recognition may be regarded as a case of transfer in terms of the paradigm for tasks of Type *SRSR*, since both stimuli and responses are identical and should lead to correct recognition. But failure of recognition could also be regarded as positive transfer, since the identical response, made to a new stimulus, would lead to an incorrect selection (recognition) response. The second principle would apply to recognition, if a subject first learned a label for, say, a form and then was asked to press a switch when that form again appeared. This would correspond to a task of Type *SRSr*, and transfer would depend on the similarity between the label and the switch-pressing response. But a question might arise over one's definition of similarity between the responses. A number of experiments, for example, have indicated that positive transfer may occur in cases where the stimuli of the two tasks are identical but where the responses are clearly different (6, 9, 11, 14, 29, 30).

A third caution in the interpretation of these principles involves the implicit assumption that transfer is related to discrimination. In terms of the model, stimuli which are least discriminable are most likely to evoke responses which may be interpreted as denoting positive transfer, but also as reflecting failure of recognition. This point need not be of major concern, but care needs to be exercised in any broad generalizations about the applicability of these kinds of principles.

Thus, we see that S–R formulations may be used in part to account for some of the findings from studies of recognition. On the other hand, some facts of recognition tasks are not in accord with these principles—indeed, even some facts of transfer are not, as noted earlier (10) —and additional hypotheses may be needed. Some of these added hypotheses may be found in studies of transfer

as related to discrimination, discussed in the next paragraphs.

STIMULUS DISCRIMINABILITY AND TRANSFER

Some studies have indicated that transfer may result from improvement in discriminability of stimuli following training. The hypotheses of these studies involve two different kinds of assumed processes. The first kind, represented in the papers of Gibson (17, 19) and Gibson and Gibson (20), assumes that differential reinforcement during learning serves to reduce the gradient of stimulus generalization. The second kind, which appears in the formulation of Miller and Dollard (33), assumes that the stimuli become more "distinctive" as a result of the addition of response-produced cues generated during learning. Both of these hypotheses involve the assumption that the operations of a learning experiment provide for development of increased stimulus discriminability. Both also postulate that discriminability thus developed persists, and is effective in a transfer task which involves differential response. Goss (21) has extended these postulates to include response relations in the two tasks. He assumes that responses made during the first task give rise to stimuli which, added to the task stimuli, make them more distinctive. He also assumes that these response-produced stimuli may be conditioned to the response of the transfer task, in addition to or independent of other conditioning. According to this view, if an instrumental response has been conditioned to a stimulus in the past, and if that stimulus is aroused by a response made in a learning task, transfer to a new task will occur by way of the relation between the response-produced stimulus and the instrumental response of the transfer task. Thus, in the experiment by Gagné and Baker, cited earlier (15), the transfer found could be accounted for on the basis that the labels learned in the first task facilitated establishment of distinctiveness by becoming part of the stimulus-complex employed in the second task. The positive transfer found by McAllister (30) could result from the preestablished relation between the label learned in the first task and the motor response of the second.

These principles may also be employed to account in part for the data of recognition studies. Added distinctiveness would reduce generalization and thus reduce the possibility of false recognitions in the second task. Pre-existing relations between responses made to the stimuli would facilitate appropriate instrumental responses which reflect recognition. In the experiment by Arnoult, for example, the addition of the label during paired-associates training could be regarded as facilitating discrimination of the old stimuli from the new, and this improved discrimination would reduce the likelihood of selection of a new form. In McAllister's study, increased relatedness of the response label to the response of switch selection, and the corresponding increase in transfer, could be regarded as reflecting correct recognition.

Here, as in the previous discussion, some qualification is needed. In terms of the paradigms cited earlier, recognition is conceived as depending upon differential response to discriminative stimuli. Pressing a correct switch when an old stimulus is presented is facilitated, presumably, by recognition resulting in part from the response of labeling. Pressing an incorrect switch may reflect failure of recognition and result in negative transfer. Conversely, as in the previous examples, recognition could result from positive transfer of a labeling response learned during the first task, and failure of recognition could result

similarly. The interpretation of a recognition experiment requires careful analysis of the S–R relations involved if they are to be used to account for the results.

VERBAL MEDIATION AND TRANSFER

Several studies have suggested that transfer may be mediated by verbal associations, established either between the stimuli of the first task and the responses of the second or between the responses of the first task and the responses of the second.

Noble (34) and Noble and McNeely (35) have shown that verbal stimuli (words, syllables, or paralogs) are learned more rapidly if they also have greater numbers of associations made to them by independent groups of subjects. Postman (37) has also emphasized the view that associations made to stimuli lend meaning to them and facilitate transfer and improve discriminability. This latter view is taken by Postman as an alternative hypothesis, concerning the development of discrimination processes, to that of Gibson and Gibson (20). As such, the associationistic hypothesis represents an additional one which may apply to recognition as well. Facilitation of transfer would result, in this view, from enrichment of the stimuli, by way of the responses made to them during the first task. Recognition would also, presumably, be improved by similar enrichment. Stated another way, the facilitation could result from an increase in the probability of occurrence of a mediating association between the stimuli of the first task and the responses of the second. In Arnoult's experiment, for example, the improved recognition of the forms for which the subjects invented their own labels may have come about as a result of the use of labels having increased meaningfulness (2) as well as belongingness, as postulated (2).

In general, according to this view, responses to old stimuli would be facilitated by virtue of associations formed during learning, and responses to new stimuli would occur only as a result of generalization from old stimuli, on the basis of similarity, as in Osgood's model (36). Similarly, if associations were formed between the responses of the learning and transfer tasks, transfer and recognition would be facilitated in a manner such as that postulated by Goss (21).

IMPLICATIONS FOR THE STUDY OF RECOGNITION

The formulations of transfer that we have outlined above may be seen to involve four kinds of assumptions which are generalizable to the study of recognition:

1. Transfer depends on the degree to which responses learned to old stimuli generalize to new stimuli. This assumption is evident in the empirical model of Osgood (36). Recognition, similarly conceived, would depend upon the discriminability of the stimuli, but would be inversely related to transfer. Selection responses, made to new stimuli, would reflect positive transfer, but also failure of discrimination and false recognition. As a working hypothesis, this proposition appears fairly obvious, but it is not easy to test in all cases. The question of specification of relevant stimulus dimensions against which to relate discriminability is particularly difficult to answer, and only a bare beginning has been made in the development of physical variables which describe complex stimuli. In the case of forms and patterns, for example, physical variables have not been clearly described in many studies, and invariant

properties of "form" which distinguish them from other "forms" have not been adequately investigated (4, 5, 28) independently of learning (5) or judgments (23). Alteration of structure (24), judgments of meaning (23), and similar variables have been used as measures of "similarity," but without a defined physical scale. The efforts of Attneave and Arnoult (5) to develop measures of forms are important advances in this direction, as are other similar attempts (28). But greater efforts are clearly required before the relation between discriminability (25) and recognition (and transfer, for that matter) may be clearly established.

2. Transfer depends on the extent to which the stimuli of the training task become differentiated or distinctive, either as a result of reduction of generalization (17) or as a result of addition of response-produced cues (21, 33). To the extent that recognition is dependent upon discriminability, by these hypotheses it too would be facilitated and related to transfer, as in Paragraph 1 above. The added hypothesis here, of course, is that discriminability may be improved by differential response training, and that it persists and facilitates recognition.

3. As a corollary to the first hypothesis above, we would add that transfer and recognition are dependent upon the degree to which response-produced stimuli are themselves discriminable or distinctive. Clearly, in Goss's formulation, if the response-produced stimuli are not discriminable, they will not add distinctiveness to the task stimuli. Here, as in the first hypothesis, the specification of physical measures of similarity of such stimuli needs to be made before adequate tests of this hypothesis may be conducted. More often than not, response-produced cues have been inferred, and more direct establishment of their existence and their measurement would constitute an important advance.

4. Transfer and recognition are dependent upon associative connections, formed during learning, and their relations both to the first-task stimuli and to the second-task responses. The probability of arousal of such associations and their relations to the second-task responses would need to be manipulated in systematic fashion in order to test this hypothesis. Although evidence exists to support the hypothesis in part, variation of both aspects (probability of occurrence and relation to the second-task response) would need to be carried out in the same experiment to obtain a clear view of the relative contribution of each. Birge, for example, found that a naming response, learned for nonsense pictures, facilitated transfer of a reaching response from one picture to another for which the same name was learned (9). Buzzotta (11) was able to alter the probability that an association would occur to a response word used in a first-task practice period, and this probability was related to transfer in a second task involving different responses. Vanderplas and Garvin [4] found that recognition was related to the degree to which the stimuli of a paired-associates task (nonsense forms) elicited associations in an independent group used to scale the forms for association value. Independent variation of these variables in the same group of subjects would extend knowledge about their importance to a considerable degree.

The above hypotheses are not regarded as mutually exclusive, in the sense that if one is true others are not. Rather, they may be conceived as representing stages in the development of transfer or recognition as a result of first-task practice. To the extent that one begins with discriminable stimuli, differential responses may be made to

different stimuli, thus (perhaps) increasing their discriminability. Associations made to the stimuli or responses may add to the likelihood of transfer, discrimination, and recognition. Differential response-produced cues, themselves discriminable, may further add to these processes, by way of their likelihood of occurrence or their likelihood of evoking instrumental responses upon which recognition depends. The relations among the hypotheses are further questions to be answered empirically.

REFERENCES

1. ARNOULT, M. D. Transfer of predifferentiation training in simple and multiple shape discrimination. *J. exp. Psychol.*, 1953, **45**, 401–409.
2. ARNOULT, M. D. Recognition of shapes following paired-associates pretraining. In G. Finch & F. Cameron (Eds.), *Symposium on Air Force human engineering, personnel, and training research.* Washington: Nat. Acad. Sci.-Nat. Res. Council Publ. No. 455, 1956, 1–9.
3. ARNOULT, M. D. Stimulus predifferentiation: Some generalizations and hypotheses. *Psychol. Bull.* 1957, **54**, 339–350.
4. ATTNEAVE, F. Physical determinants of the judged complexity of shapes. *J. exp. Psychol.*, 1957, **53**, 221–227.
5. ATTNEAVE, F., & ARNOULT, M. D. The quantitative study of shape and pattern perception. *Psychol. Bull.*, 1956, **53**, 452–471.
6. BAKER, K. E., & WYLIE, R. C. Transfer of verbal training to a motor task. *J. exp. Psychol.*, 1950, **40**, 623–638.
7. BALDWIN, R. D. Discrimination learning as a function of stimulus predifferentiation and mediated association training. Unpublished doctoral dissertation. State Univer. of Iowa, 1954.
8. BAUM, M. H. A study of concept attainment and verbal learning. Unpublished doctoral dissertation. Yale Univer., 1951.
9. BIRGE, J. S. The role of verbal response in transfer. Unpublished doctoral dissertation. Yale Univer., 1941.
10. BUGELSKI, B. R., & CADWALLADER, T. C. A reappraisal of the transfer and retroaction surface. *J. exp. Psychol.*, 1956, **52**, 360–366.
11. BUZZOTTA, V. R. Association-probability in the study of verbal behavior. Unpublished doctoral dissertation. Washington Univer., 1956.
12. CAMPBELL, V., & FREEMAN, J. T. Some functions of experimentally-induced language in perceptual learning. *Percept. mot. Skills*, 1955, **1**, 71–79.
13. CANTOR, G. N. Effects of three types of pretraining on discrimination learning in preschool children. *J. exp. Psychol.*, 1955, **49**, 339–342.
14. COFER, C. N., & FOLEY, J. P. Mediated generalization and the interpretation of verbal behavior: I. Prolegomena. *Psychol. Rev.*, 1942, **49**, 513–540.
15. GAGNÉ, R. M., & BAKER, K. E. Stimulus predifferentiation as a factor in transfer of training. *J. exp. Psychol.*, 1950, **40**, 439–451.
16. GAGNÉ, R. M., BAKER, K. E., & FOSTER, H. Transfer of discrimination training to a motor task. *J. exp. Psychol.*, 1950, **40**, 314–328.
17. GIBSON, E. J. A systematic application of the concepts of generalization and differentiation to verbal learning. *Psychol. Rev.*, 1940, **47**, 196–229.
18. GIBSON, E. J. Retroactive inhibition as a function of degree of generalization between tasks. *J. exp. Psychol.*, 1941, **28**, 93–115.
19. GIBSON, E. J. Intra-list generalization as a factor in verbal learning. *J. exp. Psychol.*, 1942, **30**, 185–200.
20. GIBSON, J. J., & GIBSON, E. J. Perceptual learning: Differentiation or enrichment? *Psychol. Rev.*, 1955, **62**, 32–41.
21. GOSS, A. E. A stimulus-response analysis of the interaction of cue-producing and instrumental responses. *Psychol. Rev.*, 1955, **62**, 20–31.
22. GRAHAM, C. H. Sensation and perception in an objective psychology. *Psychol. Rev.*, 1958, **65**, 65–76.
23. HAAGEN, C. H. Synonymity, vividness, familiarity and association ratings of 400 pairs of common adjectives. *J. Psychol.*, 1949, **27**, 453–463.
24. HAMILTON, R. J. Retroactive facilitation as a function of degree of similarity between tasks. *J. exp. Psychol.*, 1943, **32**, 363–376.
25. HOVLAND, C. I. The generalization of conditioned responses: I. The sensory generalization of conditioned responses with varying frequencies of tone. *J. gen. Psychol.*, 1937, **17**, 125–148.

26. KANFER, F. H. Perception: Identification and instrumental activity. *Psychol. Rev.*, 1956, **63**, 317–329.

27. KURTZ, K. H., & HOVLAND, C. I. The effect of verbalizations during observation of stimulus objects upon accuracy of recognition and recall. *J. exp. Psychol.*, 1953, **45**, 157–164.

28. LABERGE, D. L., & LAWRENCE, D. H. A method of generating visual forms of graded similarity. *Amer. Psychologist*, 1955, **10**, 401. (Abstract)

29. LAWRENCE, D. H. Transfer between discriminations involving the same cues but different responses. *Amer. Psychologist*, 1947, **2**, 303–304.

30. MCALLISTER, D. E. The effects of various kinds of relevant verbal pretraining on subsequent motor performance. *J. exp. Psychol.*, 1953, **46**, 329–336.

31. MCGEOCH, J. A., & IRION, A. L. *The psychology of human learning*. (2nd. ed.) New York: Longmans, Green, 1952.

32. MCKINNEY, F., & MCGEOCH, J. A. The character and extent of transfer in retroactive inhibition: Disparate serial lists. *Amer. J. Psychol.*, 1935, **47**, 409–423.

33. MILLER, N. E., & DOLLARD, J. *Social learning and imitation*. New Haven: Yale Univer. Press, 1941.

34. NOBLE, C. E. The meaning-familiarity relationship. *Psychol. Rev.*, 1953, **60**, 89–98.

35. NOBLE, C. E., & MCNEELY, D. A. The role of meaningfulness (m) in paired-associate verbal learning. *J. exp. Psychol.*, 1957, **53**, 16–22.

36. OSGOOD, C. E. The similarity paradox in human learning: A resolution. *Psychol. Rev.*, 1949, **56**, 132–143.

37. POSTMAN, L. Association theory and perceptual learning. *Psychol. Rev.*, 1955, **62**, 438–446.

38. ROBINSON, J. S. The effect of learning verbal labels for stimuli on their later discrimination. *J. exp. Psychol.*, 1955, **49**, 112–115.

39. ROSSMAN, I. L., & GOSS, A. E. The acquired distinctiveness of cues: The role of discriminative verbal responses in facilitating the acquisition of discriminative motor responses. *J. exp. Psychol.*, 1951, **42**, 173–182.

40. WOODWORTH, R. S., & SCHLOSBERG, H. *Experimental psychology*. (Rev. ed.) New York: Holt, 1955.

(Received March 21, 1958)

Psychological Review
Vol. 65, No. 6, 1958

THE PERCEPTRON: A PROBABILISTIC MODEL FOR INFORMATION STORAGE AND ORGANIZATION IN THE BRAIN[1]

F. ROSENBLATT

Cornell Aeronautical Laboratory

If we are eventually to understand the capability of higher organisms for perceptual recognition, generalization, recall, and thinking, we must first have answers to three fundamental questions:

1. How is information about the physical world sensed, or detected, by the biological system?
2. In what form is information stored, or remembered?
3. How does information contained in storage, or in memory, influence recognition and behavior?

The first of these questions is in the province of sensory physiology, and is the only one for which appreciable understanding has been achieved. This article will be concerned primarily with the second and third questions, which are still subject to a vast amount of speculation, and where the few relevant facts currently supplied by neurophysiology have not yet been integrated into an acceptable theory.

With regard to the second question, two alternative positions have been maintained. The first suggests that storage of sensory information is in the form of coded representations or images, with some sort of one-to-one mapping between the sensory stimulus and the stored pattern. According to this hypothesis, if one understood the code or "wiring diagram" of the nervous system, one should, in principle, be able to discover exactly what an organism remembers by reconstructing the original sensory patterns from the "memory traces" which they have left, much as we might develop a photographic negative, or translate the pattern of electrical charges in the "memory" of a digital computer. This hypothesis is appealing in its simplicity and ready intelligibility, and a large family of theoretical brain models has been developed around the idea of a coded, representational memory (**2**, **3**, **9**, **14**). The alternative approach, which stems from the tradition of British empiricism, hazards the guess that the images of stimuli may never really be recorded at all, and that the central nervous system simply acts as an intricate switching network, where retention takes the form of new connections, or pathways, between centers of activity. In many of the more recent developments of this position (Hebb's "cell assembly," and Hull's "cortical anticipatory goal response," for example) the "responses" which are associated to stimuli may be entirely contained within the CNS itself. In this case the response represents an "idea" rather than an action. The important feature of this approach is that there is never any simple mapping of the stimulus into memory, according to some code which would permit its later reconstruction. Whatever in-

[1] The development of this theory has been carried out at the Cornell Aeronautical Laboratory, Inc., under the sponsorship of the Office of Naval Research, Contract Nonr-2381(00). This article is primarily an adaptation of material reported in Ref. 15, which constitutes the first full report on the program.

formation is retained must somehow be stored as a *preference for a particular response;* i.e., the information is contained in *connections* or *associations* rather than topographic representations. (The term *response*, for the remainder of this presentation, should be understood to mean any distinguishable state of the organism, which may or may not involve externally detectable muscular activity. The activation of some nucleus of cells in the central nervous system, for example, can constitute a response, according to this definition.)

Corresponding to these two positions on the method of information retention, there exist two hypotheses with regard to the third question, the manner in which stored information exerts its influence on current activity. The "coded memory theorists" are forced to conclude that recognition of any stimulus involves the matching or systematic comparison of the contents of storage with incoming sensory patterns, in order to determine whether the current stimulus has been seen before, and to determine the appropriate response from the organism. The theorists in the empiricist tradition, on the other hand, have essentially combined the answer to the third question with their answer to the second: since the stored information takes the form of new connections, or transmission channels in the nervous system (or the creation of conditions which are functionally equivalent to new connections), it follows that the new stimuli will make use of these new pathways which have been created, automatically activating the appropriate response without requiring any separate process for their recognition or identification.

The theory to be presented here takes the empiricist, or "connectionist" position with regard to these questions. The theory has been developed for a hypothetical nervous system, or machine, called a *perceptron*. The perceptron is designed to illustrate some of the fundamental properties of intelligent systems in general, without becoming too deeply enmeshed in the special, and frequently unknown, conditions which hold for particular biological organisms. The analogy between the perceptron and biological systems should be readily apparent to the reader.

During the last few decades, the development of symbolic logic, digital computers, and switching theory has impressed many theorists with the functional similarity between a neuron and the simple on-off units of which computers are constructed, and has provided the analytical methods necessary for representing highly complex logical functions in terms of such elements. The result has been a profusion of brain models which amount simply to logical contrivances for performing particular algorithms (representing "recall," stimulus comparison, transformation, and various kinds of analysis) in response to sequences of stimuli—e.g., Rashevsky (**14**), McCulloch (**10**), McCulloch & Pitts (**11**), Culbertson (**2**), Kleene (**8**), and Minsky (**13**). A relatively small number of theorists, like Ashby (**1**) and von Neumann (**17, 18**), have been concerned with the problems of how an imperfect neural network, containing many random connections, can be made to perform reliably those functions which might be represented by idealized wiring diagrams. Unfortunately, the language of symbolic logic and Boolean algebra is less well suited for such investigations. The need for a suitable language for the mathematical analysis of events in systems where only the gross organization can be characterized, and the

precise structure is unknown, has led the author to formulate the current model in terms of probability theory rather than symbolic logic.

The theorists referred to above were chiefly concerned with the question of how such functions as perception and recall might be achieved by a deterministic physical system of any sort, rather than how this is actually done by the brain. The models which have been produced all fail in some important respects (absence of equipotentiality, lack of neuroeconomy, excessive specificity of connections and synchronization requirements, unrealistic specificity of stimuli sufficient for cell firing, postulation of variables or functional features with no known neurological correlates, etc.) to correspond to a biological system. The proponents of this line of approach have maintained that, once it has been shown how a physical system of any variety might be made to perceive and recognize stimuli, or perform other brainlike functions, it would require only a refinement or modification of existing principles to understand the working of a more realistic nervous system, and to eliminate the shortcomings mentioned above. The writer takes the position, on the other hand, that these shortcomings are such that a mere refinement or improvement of the principles already suggested can never account for biological intelligence; a *difference in principle* is clearly indicated. The theory of statistical separability (Cf. **15**), which is to be summarized here, appears to offer a solution in principle to all of these difficulties.

Those theorists—Hebb (**7**), Milner (**12**), Eccles (**4**), Hayek (**6**)—who have been more directly concerned with the biological nervous system and its activity in a natural environment, rather than with formally analogous machines, have generally been less exact in their formulations and far from rigorous in their analysis, so that it is frequently hard to assess whether or not the systems that they describe could actually work in a realistic nervous system, and what the necessary and sufficient conditions might be. Here again, the lack of an analytic language comparable in proficiency to the Boolean algebra of the network analysts has been one of the main obstacles. The contributions of this group should perhaps be considered as suggestions of what to look for and investigate, rather than as finished theoretical systems in their own right. Seen from this viewpoint, the most suggestive work, from the standpoint of the following theory, is that of Hebb and Hayek.

The position, elaborated by Hebb (**7**), Havek (**6**), Uttley (**16**), and Ashby (**1**), in particular, upon which the theory of the perceptron is based, can be summarized by the following assumptions:

1. The physical connections of the nervous system which are involved in learning and recognition are not identical from one organism to another. At birth, the construction of the most important networks is largely random, subject to a minimum number of genetic constraints.

2. The original system of connected cells is capable of a certain amount of plasticity; after a period of neural activity, the probability that a stimulus applied to one set of cells will cause a response in some other set is likely to change, due to some relatively long-lasting changes in the neurons themselves.

3. Through exposure to a large sample of stimuli, those which are most "similar" (in some sense which must be defined in terms of the particular physical system) will tend

to form pathways to the same sets of responding cells. Those which are markedly "dissimilar" will tend to develop connections to different sets of responding cells.

4. The application of positive and/or negative reinforcement (or stimuli which serve this function) may facilitate or hinder whatever formation of connections is currently in progress.

5. *Similarity*, in such a system, is represented at some level of the nervous system by a tendency of similar stimuli to activate the same sets of cells. Similarity is not a necessary attribute of particular formal or geometrical classes of stimuli, but depends on the physical organization of the perceiving system, an organization which evolves through interaction with a given environment. The structure of the system, as well as the ecology of the stimulus-environment, will affect, and will largely determine, the classes of "things" into which the perceptual world is divided.

THE ORGANIZATION OF A PERCEPTRON

The organization of a typical photo-perceptron (a perceptron responding to optical patterns as stimuli) is shown in Fig. 1. The rules of its organization are as follows:

1. Stimuli impinge on a retina of sensory units (S-points), which are assumed to respond on an all-or-nothing basis, in some models, or with a pulse amplitude or frequency proportional to the stimulus intensity, in other models. In the models considered here, an all-or-nothing response will be assumed.

2. Impulses are transmitted to a set of association cells (A-units) in a "projection area" (A_I). This projection area may be omitted in some models, where the retina is connected directly to the association area (A_{II}).

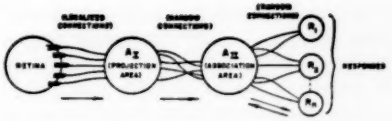


FIG. 1. Organization of a perceptron.

The cells in the projection area each receive a number of connections from the sensory points. The set of S-points transmitting impulses to a particular A-unit will be called the *origin points* of that A-unit. These origin points may be either *excitatory* or *inhibitory* in their effect on the A-unit. If the algebraic sum of excitatory and inhibitory impulse intensities is equal to or greater than the threshold (θ) of the A-unit, then the A-unit fires, again on an all-or-nothing basis (or, in some models, which will not be considered here, with a frequency which depends on the net value of the impulses received). The origin points of the A-units in the projection area tend to be clustered or focalized, about some central point, corresponding to each A-unit. The number of origin points falls off exponentially as the retinal distance from the central point for the A-unit in question increases. (Such a distribution seems to be supported by physiological evidence, and serves an important functional purpose in contour detection.)

3. Between the projection area and the association area (A_{II}), connections are assumed to be random. That is, each A-unit in the A_{II} set receives some number of fibers from origin points in the A_I set, but these origin points are scattered at random throughout the projection area. Apart from their connection distribution, the A_{II} units are identical with the A_I units, and respond under similar conditions.

4. The "responses," R_1, R_2, . . . , R_n are cells (or sets of cells) which

respond in much the same fashion as the A-units. Each response has a typically large number of origin points located at random in the A_{II} set. The set of A-units transmitting impulses to a particular response will be called the source-set for that response. (The source-set of a response is identical to its set of origin points in the A-system.) The arrows in Fig. 1 indicate the direction of transmission through the network. Note that up to A_{II} all connections are forward, and there is no feedback. When we come to the last set of connections, between A_{II} and the R-units, connections are established in both directions. The rule governing feedback connections, in most models of the perceptron, can be either of the following alternatives:

(*a*) Each response has excitatory feedback connections to the cells in its own source-set, or

(*b*) Each response has inhibitory feedback connections to the complement of its own source-set (i.e., it tends to prohibit activity in any association cells which do not transmit to it).

The first of these rules seems more plausible anatomically, since the R-units might be located in the same cortical area as their respective source-sets, making mutual excitation between the R-units and the A-units of the appropriate source-set highly probable. The alternative rule (*b*) leads to a more readily analyzed system, however, and will therefore be assumed for most of the systems to be evaluated here.

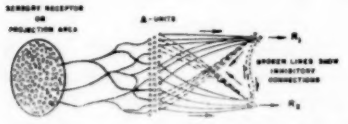


FIG. 2A. Schematic representation of connections in a simple perceptron.

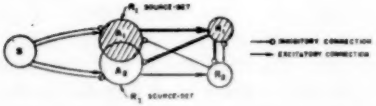


FIG. 2B. Venn diagram of the same perceptron (shading shows active sets for R_1 response).

Figure 2 shows the organization of a simplified perceptron, which affords a convenient entry into the theory of statistical separability. After the theory has been developed for this simplified model, we will be in a better position to discuss the advantages of the system in Fig. 1. The feedback connections shown in Fig. 2 are inhibitory, and go to the complement of the source-set for the response from which they originate; consequently, this system is organized according to Rule *b*, above. The system shown here has only three stages, the first association stage having been eliminated. Each A-unit has a set of randomly located origin points in the retina. Such a system will form similarity concepts on the basis of *coincident areas* of stimuli, rather than by the similarity of contours or outlines. While such a system is at a disadvantage in many discrimination experiments, its capability is still quite impressive, as will be demonstrated presently. The system shown in Fig. 2 has only two responses, but there is clearly no limit on the number that might be included.

The responses in a system organized in this fashion are mutually exclusive. If R_1 occurs, it will tend to inhibit R_2, and will also inhibit the source-set for R_2. Likewise, if R_2 should occur, it will tend to inhibit R_1. If the total impulse received from all the A-units in one source-set is stronger or more frequent than the impulse received by the alternative (antagonistic) response, then the first response will

tend to gain an advantage over the other, and will be the one which occurs. If such a system is to be capable of learning, then it must be possible to modify the A-units or their connections in such a way that stimuli of one class will tend to evoke a stronger impulse in the R_1 source-set than in the R_2 source-set, while stimuli of another (dissimilar) class will tend to evoke a stronger impulse in the R_2 source-set than in the R_1 source-set.

It will be assumed that the impulses delivered by each A-unit can be characterized by a value, V, which may be an amplitude, frequency, latency, or probability of completing transmission. If an A-unit has a high value, then all of its output impulses are considered to be more effective, more potent, or more likely to arrive at their endbulbs than impulses from an A-unit with a lower value. The value of an A-unit is considered to be a fairly stable characteristic, probably depending on the metabolic condition of the cell and the cell membrane, but it is not absolutely constant. It is assumed that, in general, periods of activity tend to increase a cell's value, while the value may decay (in some models) with inactivity. The most interesting models are those in which cells are assumed to compete for metabolic materials, the more active cells gaining at the expense of the less active cells. In such a system, if there is no activity, all cells will tend to remain in a relatively constant condition, and (regardless of activity) the net value of the system, taken in

TABLE 1

COMPARISON OF LOGICAL CHARACTERISTICS OF α, β, AND γ SYSTEMS

	α-System (Uncompensated Gain System)	β-System (Constant Feed System)	γ-System (Parasitic Gain System)
Total value-gain of source set per reinforcement	N_{a_r}	K	0
ΔV for A-units active for 1 unit of time	$+1^{\prime}$	K/N_{a_r}	$+1$
ΔV for inactive A-units outside of dominant set	0	K/N_{A_r}	0
ΔV for inactive A-units of dominant set	0	0	$\frac{-N_{a_r}}{N_{A_r}-N_{a_r}}$
Mean value of A-system	Increases with number of reinforcements	Increases with time	Constant
Difference between mean values of source-sets	Proportional to differences of reinforcement frequency $(n_{s_{r_1}}-n_{s_{r_2}})$	0	0

Note: In the β and γ systems, the total value-change for any A-unit will be the sum of the ΔV's for all source-sets of which it is a member.

N_{a_r} = Number of active units in source-set
N_{A_r} = Total number of units in source-set
$n_{s_{r_i}}$ = Number of stimuli associated to response r_i
K = Arbitrary constant

its entirety, will remain constant at all times. Three types of systems, which differ in their value dynamics, have been investigated quantitatively. Their principal logical features are compared in Table 1. In the alpha system, an active cell simply gains an increment of value for every impulse, and holds this gain indefinitely. In the beta system, each source-set is allowed a certain constant rate of gain, the increments being apportioned among the cells of the source-set in proportion to their activity. In the gamma system, active cells gain in value at the expense of the inactive cells of their source-set, so that the total value of a source-set is always constant.

For purposes of analysis, it is convenient to distinguish two phases in the response of the system to a stimulus (Fig. 3). In the *predominant phase*, some proportion of A-units (represented by solid dots in the figure) responds to the stimulus, but the R-units are still inactive. This phase is transient, and quickly gives way to the *postdominant phase*, in which one of the responses becomes active, inhibiting activity in the complement of its own source-set, and thus preventing the occurrence of any alternative response. The response which happens to become dominant is initially random, but if the A-units are reinforced (i.e., if the active units are allowed to gain in value), then when the same stimulus is presented again at a later time, the same response will have a stronger tendency to recur, and learning can be said to have taken place.

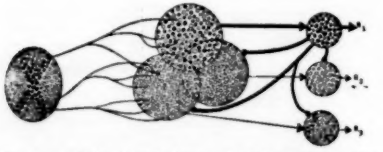


FIG. 3A. Predominant phase. Inhibitory connections are not shown. Solid black units are active.

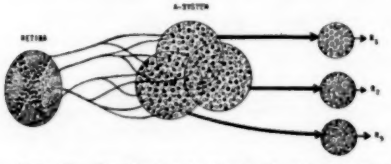


FIG. 3B. Postdominant phase. Dominant subset suppresses rival sets. Inhibitory connections shown only for R_1.

FIG 3. Phases of response to a stimulus.

ANALYSIS OF THE PREDOMINANT PHASE

The perceptrons considered here will always assume a fixed threshold, θ, for the activation of the A-units. Such a system will be called a *fixed-threshold model*, in contrast to a *continuous transducer model*, where the response of the A-unit is some continuous function of the impinging stimulus energy.

In order to predict the learning curves of a fixed-threshold perceptron, two variables have been found to be of primary importance. They are defined as follows:

P_a = the expected proportion of A-units activated by a stimulus of a given size,

P_c = the conditional probability that an A-unit which responds to a given stimulus, S_1, will also respond to another given stimulus, S_2.

It can be shown (Rosenblatt, **15**) that as the size of the retina is increased, the number of S-points (N_s) quickly ceases to be a significant parameter, and the values of P_a and P_c approach the value that they would have for a retina with infinitely many points. For a large retina, therefore, the equations are as follows:

$$P_a = \sum_{e=\theta}^{s} \sum_{i=\theta}^{\min(y,\, e-\theta)} P(e,i) \qquad (1)$$

where

$$P(e,i) = \binom{x}{e} R^e(1-R)^{x-e} \times \binom{y}{i} R^i(1-R)^{y-i}$$

and

R = proportion of S-points activated by the stimulus
x = number of excitatory connections to each A-unit
y = number of inhibitory connections to each A-unit
θ = threshold of A-units.

(The quantities e and i are the excitatory and inhibitory components of the excitation received by the A-unit from the stimulus. If the algebraic sum $\alpha = e + i$ is equal to or greater than θ, the A-unit is assumed to respond.)

$$P_c = \frac{1}{P_a} \sum_{e=\theta}^{x} \sum_{i=e-\theta}^{y} \sum_{l_e=0}^{e} \sum_{l_i=0}^{i} \sum_{g_e=0}^{x-e} \sum_{g_i=0}^{y-i} P(e,i,l_e,l_i,g_e,g_i) \quad (2)$$

$$(e - i - l_e + l_i + g_e - g_i \geq \theta)$$

where

$$P(e,i,l_e,l_i,g_e,g_i) = \binom{x}{e} R^e(1-R)^{x-e} \times \binom{y}{i} R^i(1-R)^{y-i} \times \binom{e}{l_e} L^{l_e}(1-L)^{e-l_e} \times \binom{i}{l_i} L^{l_i}(1-L)^{i-l_i} \times \binom{x-e}{g_e} G^{g_e}(1-G)^{x-e-g_e} \times \binom{y-i}{g_i} G^{g_i}(1-G)^{y-i-g_i}$$

and

L = proportion of the S-points illuminated by the first stimulus, S_1, which are not illuminated by S_2
G = proportion of the residual S-set (left over from the first stimulus) which is included in the second stimulus (S_2).

The quantities R, L, and G specify the two stimuli and their retinal overlap. l_e and l_i are, respectively, the numbers of excitatory and inhibitory origin points "lost" by the A-unit when stimulus S_1 is replaced by S_2; g_e and g_i are the numbers of excitatory and inhibitory origin points "gained" when stimulus S_1 is replaced by S_2. The summations in Equation 2 are between the limits indicated, subject to the side condition $e - i - l_e + l_i + g_e - g_i \geq \theta$.

Some of the most important characteristics of P_a are illustrated in Fig. 4, which shows P_a as a function of the retinal area illuminated (R). Note that P_a can be reduced in magnitude by either increasing the threshold, θ, or by increasing the proportion of inhibitory connections (y). A comparison of Fig. 4b and 4c shows that if the excitation is about equal to the inhibition, the curves for P_a as a function of R are flattened out, so that there is little variation in P_a for stimuli of different sizes. This fact is of great importance for systems which require P_a to be close to an optimum value in order to perform properly.

The behavior of P_c is illustrated in Fig. 5 and 6. The curves in Fig. 5 can be compared with those for P_a in Fig. 4. Note that as the threshold is increased, there is an even sharper reduction in the value of P_c than was the case with P_a. P_c also decreases as the proportion of inhibitory connections increases, as does P_a. Fig. 5, which is

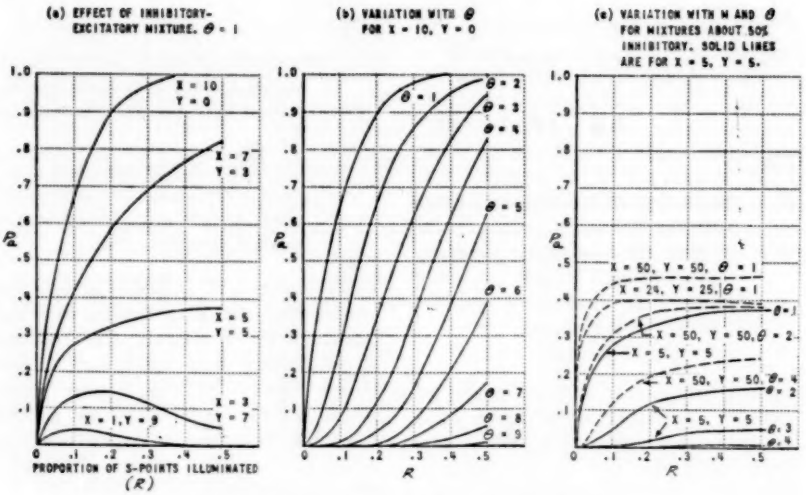

(a) EFFECT OF INHIBITORY-EXCITATORY MIXTURE. θ = 1
X = 10 Y = 0
X = 7 Y = 3
X = 5 Y = 5
X = 3 Y = 7
X = 1, Y = 9
PROPORTION OF S-POINTS ILLUMINATED (R)
(b) VARIATION WITH θ FOR X = 10, Y = 0
θ = 1
θ = 2
θ = 3
θ = 4
θ = 5
θ = 6
θ = 7
θ = 8
θ = 9
R
(c) VARIATION WITH M AND θ FOR MIXTURES ABOUT 50% INHIBITORY. SOLID LINES ARE FOR X = 5, Y = 5.
X = 50, Y = 50, θ = 1
X = 24, Y = 25, θ = 1
X = 50, Y = 50, θ = 2
X = 5, Y = 5
X = 50, Y = 50, θ = 4
X = 5, Y = 5
R

FIG. 4. P_e as function of retinal area illuminated.

calculated for nonoverlapping stimuli, illustrates the fact that P_e remains greater than zero even when the stimuli are completely disjunct, and illuminate no retinal points in common. In Fig. 6, the effect of varying amounts of overlap between the stimuli is shown. In all cases, the value of P_e goes to unity as the stimuli approach perfect identity. For smaller stimuli (broken line curves), the value of P_e is lower than for large stimuli. Similarly, the value is less for high thresholds than for low thresholds. The minimum value of P_e will be equal to

$$P_{emin} = (1 - L)^z(1 - G)^v. \quad (3)$$

In Fig. 6, P_{emin} corresponds to the curve for $\theta = 10$. Note that under these conditions the probability that the A-unit responds to both stimuli (P_e) is practically zero, except for stimuli which are quite close to identity. This condition can be of considerable help in discrimination learning.

MATHEMATICAL ANALYSIS OF LEARNING IN THE PERCEPTRON

The response of the perceptron in the predominant phase, where some fraction of the A-units (scattered throughout the system) responds to the stimulus, quickly gives way to the postdominant response, in which activity is limited to a single source-set, the other sets being suppressed. Two possible systems have been studied for the determination of the "dominant" response, in the postdominant phase. In one (the mean-discriminating system, or μ-system), the response whose inputs have the greatest mean value responds first, gaining a slight advantage over the others, so that it quickly becomes dominant. In the second case (the sum-discriminating system, or Σ-system), the response whose inputs have the greatest net value gains an advantage. In most cases, systems which respond to mean values have an advantage over systems which respond to sums, since the means are

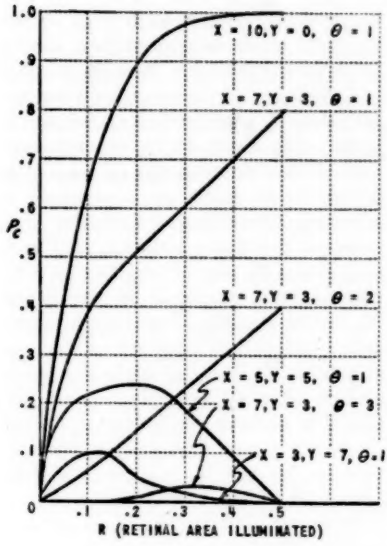


FIG. 5. P_c as a function of R, for nonoverlapping stimuli.

less influenced by random variations in P_a from one source-set to another. In the case of the γ-system (see Table 1), however, the performance of the μ-system and Σ-system become identical.

We have indicated that the perceptron is expected to learn, or to form associations, as a result of the changes in value that occur as a result of the activity of the association cells. In evaluating this learning, one of two types of hypothetical experiments can be considered. In the first case, the perceptron is exposed to some series of stimulus patterns (which might be presented in random positions on the retina) and is "forced" to give the desired response in each case. (This forcing of responses is assumed to be a prerogative of the experimenter. In experiments intended to evaluate trial-and-error learning, with more sophisticated perceptrons, the experimenter does not force the system to respond in the desired fashion, but merely applies positive reinforcement when the response happens to be correct, and negative reinforcement when the response is wrong.) In evaluating the learning which has taken place during this "learning series," the perceptron is assumed to be "frozen" in its current condition, no further value changes being allowed, and the same series of stimuli is presented again in precisely the same fashion, so that the stimuli fall on identical positions on the retina. The probability that the perceptron will show a bias towards the "correct" response (the one which has been previously reinforced during the learning series) in preference to any given alternative response is called P_r, the probability of correct choice of response between two alternatives.

In the second type of experiment, a learning series is presented exactly as before, but instead of evaluating the perceptron's performance using the same series of stimuli which were shown before, a new series is presented, in which stimuli may be drawn from the same *classes* that were previ-

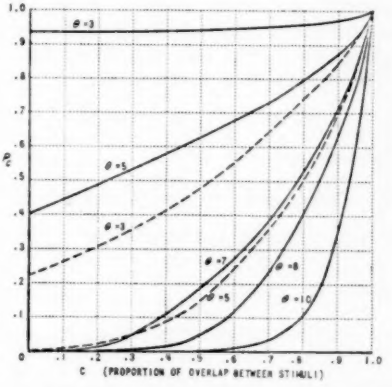


FIG. 6. P_c as a function of C. $X = 10$, $Y = 0$. Solid lines: R = .5; broken lines: R = .2.

ously experienced, but are not necessarily identical. This new test series is assumed to be composed of stimuli projected onto random retinal positions, which are chosen independently of the positions selected for the learning series. The stimuli of the test series may also differ in size or rotational position from the stimuli which were previously experienced. In this case, we are interested in the probability that the perceptron will give the correct response for the *class* of stimuli which is represented, regardless of whether the particular stimulus has been seen before or not. This probability is called P_g, the probability of correct generalization. As with P_r, P_g is actually the probability that a bias will be found in favor of the proper response rather than any one alternative; only one pair of responses at a time is considered, and the fact that the response bias is correct in one pair does not mean that there may not be other pairs in which the bias favors the wrong response. The probability that the correct response will be preferred over *all* alternatives is designated P_R or P_G.

In all cases investigated, a single general equation gives a close approximation to P_r and P_g, if the appropriate constants are substituted. This equation is of the form:

$$P = P(N_{a_r} > 0) \cdot \phi(Z) \qquad (4)$$

where

$$P(N_{a_r} > 0) = 1 - (1 - P_a)^{N_e}$$

$\phi(Z)$ = normal curve integral from $-\infty$ to Z

and

$$Z = \frac{c_1 n_{s_r} + c_2}{\sqrt{c_3 n_{s_r}^2 + c_4 n_{s_r}}}.$$

If R_1 is the "correct" response, and R_2 is the alternative response under consideration, Equation 4 is the probability that R_1 will be preferred over R_2 after n_{s_r} stimuli have been shown for each of the two responses, during the learning period. N_e is the number of "effective" A-units in each source-set; that is, the number of A-units in either source-set which are not connected in common to both responses. Those units which are connected in common contribute equally to both sides of the value balance, and consequently do not affect the net bias towards one response or the other. N_{a_r} is the number of active units in a source-set, which respond to the test stimulus, S_t. $P(N_{a_r} > 0)$ is the probability that at least one of the N_e effective units in the source-set of the correct response (designated, by convention, as the R_1 response) will be activated by the test stimulus, S_t.

In the case of P_g, the constant c_2 is always equal to zero, the other three constants being the same as for P_r. The values of the four constants depend on the parameters of the physical nerve net (the perceptron) and also on the organization of the stimulus environment.

The simplest cases to analyze are those in which the perceptron is shown stimuli drawn from an "ideal environment," consisting of randomly placed points of illumination, where there is no attempt to classify stimuli according to intrinsic similarity. Thus, in a typical learning experiment, we might show the perceptron 1,000 stimuli made up of random collections of illuminated retinal points, and we might arbitrarily reinforce R_1 as the "correct" response for the first 500 of these, and R_2 for the remaining 500. This environment is "ideal" only in the sense that we speak of an ideal gas in physics; it is a convenient artifact for purposes of analysis, and does not lead to the best performance from the perceptron. In the ideal environment situation, the constant c_1 is always equal to zero, so that, in the

case of P_0 (where c_2 is also zero), the value of Z will be zero, and P_0 can never be any better than the random expectation of 0.5. The evaluation of P_r for these conditions, however, throws some interesting light on the differences between the alpha, beta, and gamma systems (Table 1).

First consider the alpha system, which has the simplest dynamics of the three. In this system, whenever an A-unit is active for one unit of time, it gains one unit of value. We will assume an experiment, initially, in which N_{s_r} (the number of stimuli associated to each response) is constant for all responses. In this case, for the sum system,

$$\left.\begin{aligned} c_1 &= 0 \\ c_2 &= (1 - P_a)N_r \\ c_3 &= 2P_a\omega \\ c_4 &\approx 0 \end{aligned}\right\} \qquad (5)$$

where ω = the fraction of responses connected to each A-unit. If the source-sets are disjunct, $\omega = 1/N_R$, where N_R is the number of responses in the system. For the μ-system,

$$\left.\begin{aligned} c_1 &= 0 \\ c_2 &= (1 - P_a)N_r \\ c_3 &= 0 \\ c_4 &= 2\omega \end{aligned}\right\} \qquad (6)$$

The reduction of c_3 to zero gives the μ-system a definite advantage over the Σ-system. Typical learning curves for these systems are compared in Fig. 7 and 8. Figure 9 shows the effect of variations in P_a upon the performance of the system.

If n_{s_r}, instead of being fixed, is treated as a random variable, so that the number of stimuli associated to each response is drawn separately from some distribution, then the per-

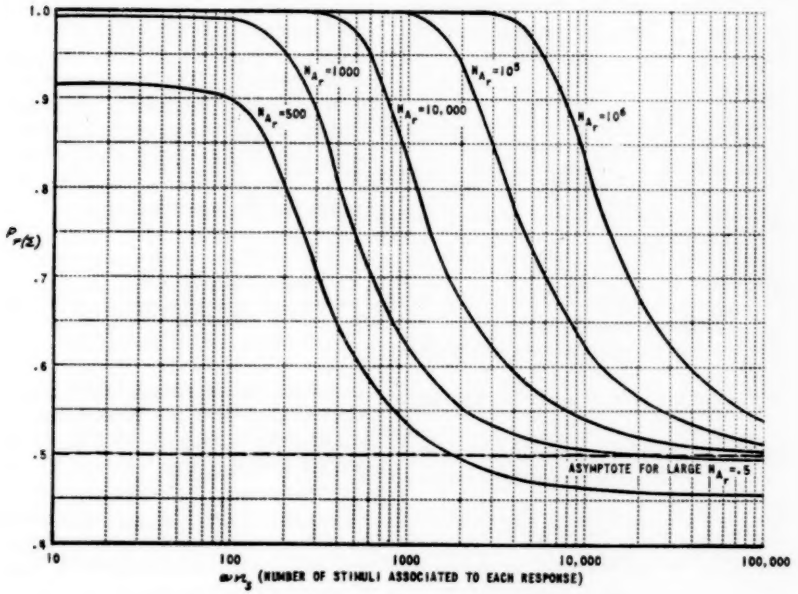


FIG. 7. $P_r(\Sigma)$ as function of ωn_{s_r}, for discrete subsets. ($\omega_e = 0$, $P_a = .005$. Ideal environment assumed.)

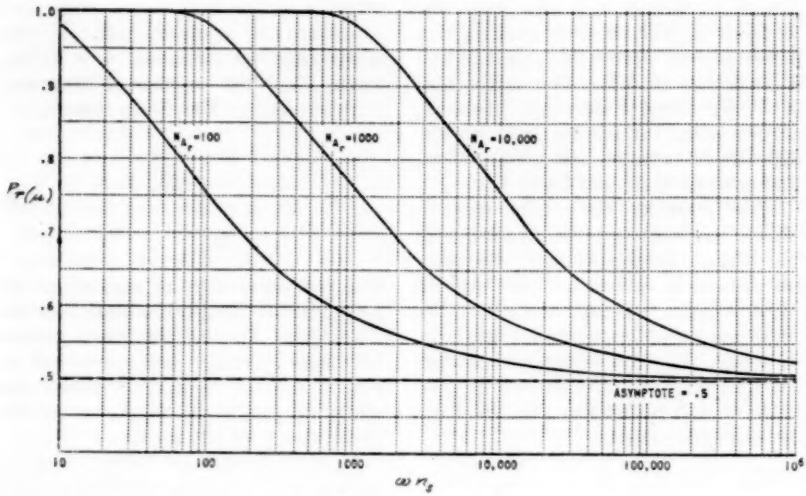


FIG. 8. $P_{r(\mu)}$ as function of ωn_s. (For $P_a = .07$, $\omega_c = 0$. Ideal environment assumed.)

formance of the α-system is considerably poorer than the above equations indicate. Under these conditions, the constants for the μ-system are

$$\left.\begin{aligned} c_1 &= 0 \\ c_2 &= 1 - P_a \\ c_3 &= 2P_a^2q^2\left[\frac{(\omega N_R - 1)^2}{N_R - 2} + 1\right] \\ c_4 &= \frac{2(1 - P_a)N_R}{(1 - \omega_c)N_A} \end{aligned}\right\} \quad (7)$$

where

q = ratio of $\sigma_{n_{sr}}$ to $\bar{n}_{sr}$
N_R = number of responses in the system
N_A = number of A-units in the system
ω_c = proportion of A-units common to R_1 and R_2.

For this equation (and any others in which n_{sr} is treated as a random variable), it is necessary to define n_{sr} in Equation 4 as the expected value of this variable, over the set of all responses.

For the β-system, there is an even greater deficit in performance, due to the fact that the net value continues to grow regardless of what happens to the system. The large net values of the subsets activated by a stimulus tend to amplify small statistical differences, causing an unreliable performance. The constants in this case (again for the μ-system) are

$$\left.\begin{aligned} c_1 &= 0 \\ c_2 &= (1 - P_a)N_e \\ c_3 &= 2(P_aN_eq\omega N_R^2)^2 \\ c_4 &= 2(1 - P_a)\omega N_RN_e \end{aligned}\right\} \quad (8)$$

In both the alpha and beta systems, performance will be poorer for the sum-discriminating model than for the mean-discriminating case. In the gamma-system, however, it can be shown that $P_{r(\Sigma)} = P_{r(\mu)}$; i.e., it makes no difference in performance whether the Σ-system or μ-system is used. Moreover, the constants for the γ-system, with variable n_{sr}, are identical to the constants for the alpha μ-sys-

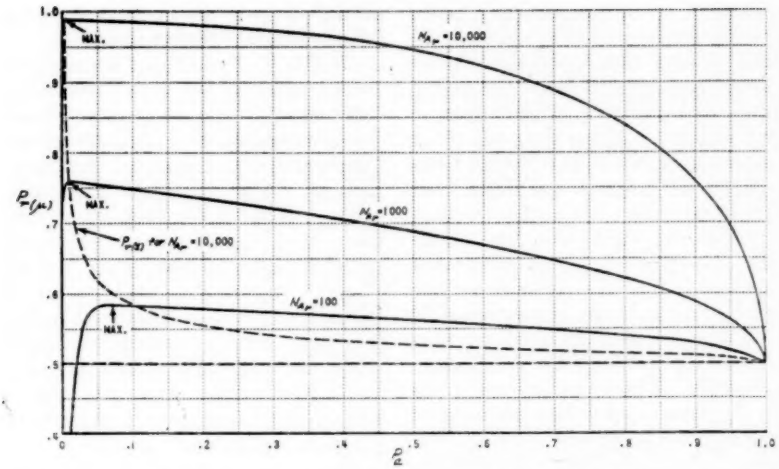


FIG. 9. $P_{r(\mu)}$ as function of P_a. (For $n_{s_r} = 1{,}000$, $\omega_0 = 0$. Ideal environment assumed.)

tem, with n_{s_r} fixed (Equation 6). The performance of the three systems is compared in Fig. 10, which clearly demonstrates the advantage of the γ-system.

Let us now replace the "ideal en-

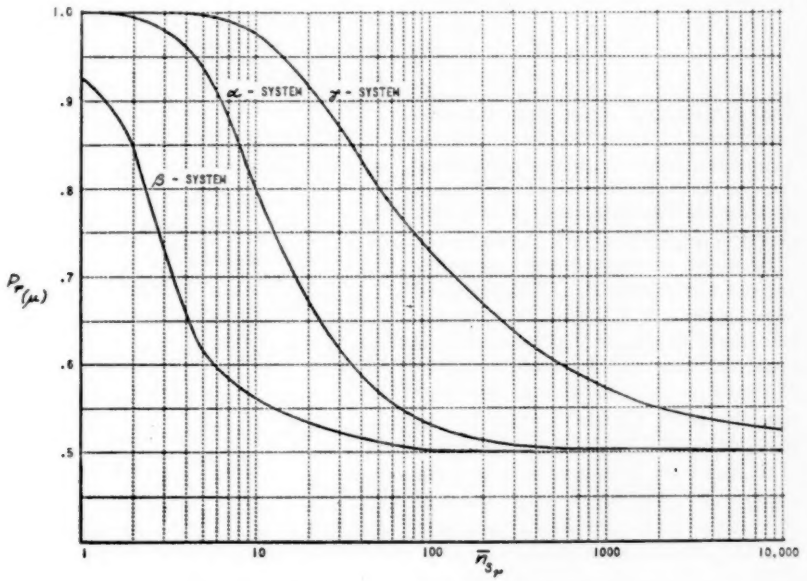


FIG. 10. Comparison of α, β, and γ systems, for variable n_{s_r} ($N_R = 100$, $\sigma_{n_{s_r}} = .5\bar{n}_{s_r}$, $N_A = 10{,}000$, $P_0 = .07$, $\omega = .2$).

vironment" assumptions with a model for a "differentiated environment," in which several distinguishable classes of stimuli are present (such as squares, circles, and triangles, or the letters of the alphabet). If we then design an experiment in which the stimuli associated to each response are drawn from a different class, then the learning curves of the perceptron are drastically altered. The most important difference is that the constant c_1 (the coefficient of n_{s_r} in the numerator of Z) is no longer equal to zero, so that Equation 4 now has a nonrandom asymptote. Moreover, in the form for P_g (the probability of correct generalization), where $c_2 = 0$, the quantity Z remains greater than zero, and P_g actually approaches the same asymptote as P_r. Thus the equation for the perceptron's performance after infinite experience with each class of stimuli is identical for P_r and P_g:

$$P_{r\infty} = P_{g\infty} = [1 - (1 - P_a)^{N_e}] \times \phi\left(\frac{c_1}{\sqrt{c_3}}\right) \quad (9)$$

This means that *in the limit it makes no difference whether the perceptron has seen a particular test stimulus before or not; if the stimuli are drawn from a differentiated environment, the performance will be equally good in either case.*

In order to evaluate the performance of the system in a differentiated environment, it is necessary to define the quantity $P_{c\alpha\beta}$. This quantity is interpreted as the expected value of P_c between pairs of stimuli drawn at random from classes α and β. In particular, P_{c11} is the expected value of P_c between members of the same class, and P_{c12} is the expected value of P_c between an S_1 stimulus drawn from Class 1 and an S_2 stimulus drawn from Class 2. P_{c1x} is the expected value of P_c between members of Class 1 and stimuli drawn at random from all other classes in the environment.

If $P_{c11} > P_a > P_{c12}$, the limiting performance of the perceptron ($P_{g\infty}$) will be better than chance, and learning of some response, R_1, as the proper "generalization response" for members of Class 1 should eventually occur. If the above inequality is not met, then improvement over chance performance may not occur, and the Class 2 response is likely to occur instead. It can be shown (**15**) that for most simple geometrical forms, which we ordinarily regard as "similar," the required inequality can be met, if the parameters of the system are properly chosen.

The equation for P_r, for the sum-discriminating version of an α-perceptron, in a differentiated environment where n_{s_r} is fixed for all responses, will have the following expressions for the four coefficients:

$$\left.\begin{aligned}
c_1 &= P_a N_e (P_{c11} - P_{c12}) \\
c_2 &= P_a N_e (1 - P_{c11}) \\
c_3 &= \sum_{r=1,2} P_a (1 - P_a) N_e \\
&\quad \times [P_{c^2 1r} + \sigma_s^2(P_{c1r}) \\
&\quad + \sigma_j^2(P_{c1r})] + (\omega N_R - 1)^2 \\
&\quad \times (P_{c1x} + \sigma_s^2(P_{c1x}) \\
&\quad + \sigma_j^2(P_{crx})) + 2(\omega N_R - 1) \\
&\quad (P_{c1r} P_{c1x})] + P_a^2 N_e^2 \\
&\quad \times [\sigma_s^2(P_{c1r}) + (\omega N_R - 1)^2 \\
&\quad \times \sigma_s^2(P_{c1x}) + 2(\omega N_R - 1)\epsilon] \\
c_4 &= \sum_{r=1,2} P_a N_e [P_{c1r} - P_{c1r}^2 \\
&\quad - \sigma_s^2(P_{c1r}) - \sigma_j^2(P_{c1r}) \\
&\quad + (\omega N_R - 1)(P_{c1x} - P_{c1x}^2 \\
&\quad - \sigma_j^2(P_{c1x}))]
\end{aligned}\right\} \quad (10)$$

where

$\sigma_s^2(P_{c1r})$ and $\sigma_s^2(P_{c1x})$ represent the variance of P_{c1r} and P_{c1x} measured over the set of possible test stimuli, S_t, and

$\sigma_j^2(P_{c1r})$ and $\sigma_j^2(P_{c1x})$ represent the variance of P_{c1r} and P_{c1x} measured over the set of all A-units, a_j.

ϵ = covariance of $P_{c1r}P_{c1x}$, which is assumed to be negligible.

The variances which appear in these expressions have not yielded, thus far, to a precise analysis, and can be treated as empirical variables to be determined for the classes of stimuli in question. If the sigma is set equal to half the expected value of the variable, in each case, a conservative estimate can be obtained. When the stimuli of a given class are all of the same shape, and uniformly distributed over the retina, the subscript s variances are equal to zero. $P_{g(\Sigma)}$ will be represented by the same set of coefficients, except for c_2, which is equal to zero, as usual.

For the mean-discriminating system, the coefficients are:

$$\left.\begin{aligned}
c_1 &= (P_{c11}-P_{c12})\\
c_2 &= (1-P_{c11})\\
c_3 &= \sum_{r=1,2}\left[\frac{1}{P_a(N_e-1)}-\frac{1}{N_e-1}\right]\\
&\quad\times[\sigma_j^2(P_{c1r})+(\omega N_R-1)^2\\
&\quad\times\sigma_j^2(P_{c1x})]+[\sigma_s^2(P_{c1r})\\
&\quad+(\omega N_R-1)^2\sigma_s^2(P_{c1x})]\\
c_4 &= \sum_{r=1,2}\frac{1}{P_aN_e}[P_{c1r}-P_{c1r}^2\\
&\quad-\sigma_s^2(P_{c1r})-\sigma_j^2(P_{c1r})\\
&\quad+(\omega N_R-1)(P_{c1x}-P_{c1x}^2\\
&\quad-\sigma_s^2(P_{c1x})-\sigma_j^2(P_{c1x}))]
\end{aligned}\right\} \quad (11)$$

Some covariance terms, which are considered negligible, have been omitted here.

A set of typical learning curves for the differentiated environment model is shown in Fig. 11, for the mean-discriminating system. The parameters are based on measurements for a

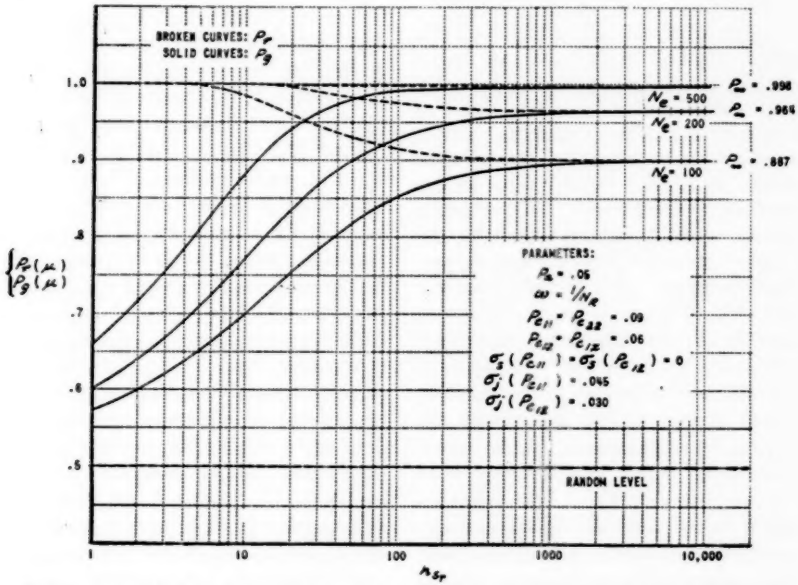


FIG. 11. P_r and P_g as function of n_{s_r}. Parameters based on square-circle discrimination.

square-circle discrimination problem. Note that the curves for P_r and P_g both approach the same asymptotes, as predicted. The values of these asymptotes can be obtained by substituting the proper coefficients in Equation 9. As the number of association cells in the system increases, the asymptotic learning limit rapidly approaches unity, so that for a system of several thousand cells, the errors in performance should be negligible on a problem as simple as the one illustrated here.

As the number of responses in the system increases, the performance becomes progressively poorer, if every response is made mutually exclusive of all alternatives. One method of avoiding this deterioration (described in detail in Rosenblatt, **15**) is through the binary coding of responses. In this case, instead of representing 100 different stimulus patterns by 100 distinct, mutually exclusive responses, a limited number of discriminating features is found, each of which can be independently recognized as being present or absent, and consequently can be represented by a single pair of mutually exclusive responses. Given an ideal set of binary characteristics (such as dark, light; tall, short; straight, curved; etc.), 100 stimulus classes could be distinguished by the proper configuration of only seven response pairs. In a further modification of the system, a single response is capable of denoting by its activity or inactivity the presence or absence of each binary characteristic. The efficiency of such coding depends on the number of independently recognizable "earmarks" that can be found to differentiate stimuli. If the stimulus can be identified only in its entirety and is not amenable to such analysis, then ultimately a separate binary response pair, or bit, is required to denote the presence or absence of each stimulus class (e.g., "dog" or "not dog"), and nothing has been gained over a system where all responses are mutually exclusive.

BIVALENT SYSTEMS

In all of the systems analyzed up to this point, the increments of value gained by an active A-unit, as a result of reinforcement or experience, have always been *positive*, in the sense that an active unit has always *gained* in its power to activate the responses to which it is connected. In the gamma-system, it is true that some units lose value, but these are always the *inactive units*, the active ones gaining in proportion to their rate of activity. In a *bivalent system*, two types of reinforcement are possible (positive and negative), and an active unit may either gain or lose in value, depending on the momentary state of affairs in the system. If the positive and negative reinforcement can be controlled by the application of external stimuli, they become essentially equivalent to "reward" and "punishment," and can be used in this sense by the experimenter. Under these conditions, a perceptron appears to be capable of trial-and-error learning. A bivalent system need not necessarily involve the application of reward and punishment, however. If a binary-coded response system is so organized that there is a single response or response-pair to represent each "bit," or stimulus characteristic that is learned, with positive feedback to its own source-set if the response is "on," and negative feedback (in the sense that active A-units will lose rather than gain in value) if the response is "off," then the system is still bivalent in its characteristics. Such a bivalent

system is particularly efficient in reducing some of the bias effects (preference for the wrong response due to greater size or frequency of its associated stimuli) which plague the alternative systems.

Several forms of bivalent systems have been considered (**15**, Chap. VII). The most efficient of these has the following logical characteristics.

If the system is under a state of positive reinforcement, then a positive ΔV is added to the values of all active A-units in the source-sets of "on" responses, while a negative ΔV is added to the active units in the source-sets of "off" responses. If the system is currently under negative reinforcement, then a negative ΔV is added to all active units in the source-set of an "on" response, and a positive ΔV is added to active units in an "off" source-set. If the source-sets are disjunct (which is essential for this system to work properly), the equation for a bivalent γ-system has the same coefficients as the monovalent α-system, for the μ-case (Equation 11).

The performance curves for this system are shown in Fig. 12, where the asymptotic generalization probability attainable by the system is plotted for the same stimulus parameters that were used in Fig. 11. This is the probability that all bits in an n-bit response pattern will be correct. Clearly, if a majority of correct responses is sufficient to identify a stimulus correctly, the performance will be better than these curves indicate.

In a form of bivalent system which utilizes more plausible biological assumptions, A-units may be either excitatory or inhibitory in their effect on connected responses. A positive ΔV in this system corresponds to the incrementing of an excitatory unit, while a negative ΔV corresponds to the incrementing of an inhibitory unit. Such a system performs similarly to the one considered above, but can be shown to be less efficient.

Bivalent systems similar to those illustrated in Fig. 12 have been simulated in detail in a series of experiments with the IBM 704 computer at the Cornell Aeronautical Laboratory. The results have borne out the theory in all of its main predictions, and will be reported separately at a later time.

IMPROVED PERCEPTRONS AND SPONTANEOUS ORGANIZATION

The quantitative analysis of perceptron performance in the preceding sections has omitted any consideration of *time* as a stimulus dimension. A perceptron which has no capability for temporal pattern recognition is referred to as a "momentary stimulus perceptron." It can be shown (**15**) that the same principles of statistical separability will permit the perceptron to distinguish velocities, sound sequences, etc., provided the stimuli leave some temporarily persistent trace, such as an altered threshold,

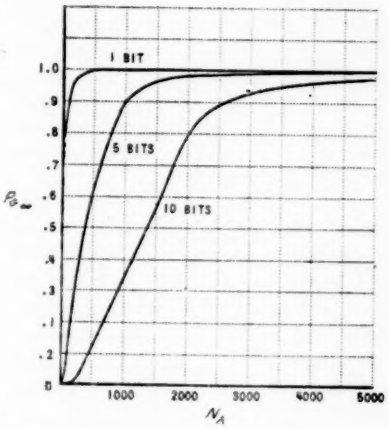


FIG. 12. P_{G_∞} for a bivalent binary system (same parameters as Fig. 11).

which causes the activity in the A-system at time t to depend to some degree on the activity at time $t - 1$.

It has also been assumed that the origin points of A-units are completely random. It can be shown that by a suitable organization of origin points, in which the spatial distribution is constrained (as in the projection area origins shown in Fig. 1), the A-units will become particularly sensitive to the location of contours, and performance will be improved.

In a recent development, which we hope to report in detail in the near future, it has been proven that if the values of the A-units are allowed to decay at a rate proportional to their magnitude, a striking new property emerges: the perceptron becomes capable of "spontaneous" concept formation. That is to say, if the system is exposed to a random series of stimuli from two "dissimilar" classes, and all of its responses are automatically reinforced without any regard to whether they are "right" or "wrong," the system will tend towards a stable terminal condition in which (for each binary response) the response will be "1" for members of one stimulus class, and "0" for members of the other class; i.e., the perceptron will spontaneously recognize the difference between the two classes. This phenomenon has been successfully demonstrated in simulation experiments, with the 704 computer.

A perceptron, even with a single logical level of A-units and response units, can be shown to have a number of interesting properties in the field of selective recall and selective attention. These properties generally depend on the intersection of the source sets for different responses, and are elsewhere discussed in detail (**15**). By combining audio and photo inputs, it is possible to associate sounds, or auditory "names" to visual objects, and to get the perceptron to perform such selective responses as are designated by the command "Name the object on the left," or "Name the color of this stimulus."

The question may well be raised at this point of where the perceptron's capabilities actually stop. We have seen that the system described is sufficient for pattern recognition, associative learning, and such cognitive sets as are necessary for selective attention and selective recall. The system appears to be potentially capable of temporal pattern recognition, as well as spatial recognition, involving any sensory modality or combination of modalities. It can be shown that with proper reinforcement it will be capable of trial-and-error learning, and can learn to emit ordered sequences of responses, provided its own responses are fed back through sensory channels.

Does this mean that the perceptron is capable, without further modification in principle, of such higher order functions as are involved in human speech, communication, and thinking? Actually, the limit of the perceptron's capabilities seems to lie in the area of relative judgment, and the abstraction of relationships. In its "symbolic behavior," the perceptron shows some striking similarities to Goldstein's brain-damaged patients (**5**). Responses to definite, concrete stimuli can be learned, even when the proper response calls for the recognition of a number of simultaneous qualifying conditions (such as naming the color if the stimulus is on the left, the shape if it is on the right). As soon as the response calls for the recognition of a relationship between stimuli (such as "Name the object left of the square." or "Indicate the pattern that appeared before the circle."), however, the

problem generally becomes excessively difficult for the perceptron. Statistical separability alone does not provide a sufficient basis for higher order abstraction. Some system, more advanced in principle than the perceptron, seems to be required at this point.

CONCLUSIONS AND EVALUATION

The main conclusions of the theoretical study of the perceptron can be summarized as follows:

1. In an environment of random stimuli, a system consisting of randomly connected units, subject to the parametric constraints discussed above, can learn to associate specific responses to specific stimuli. Even if many stimuli are associated to each response, they can still be recognized with a better-than-chance probability, although they may resemble one another closely and may activate many of the same sensory inputs to the system.

2. In such an "ideal environment," the probability of a correct response diminishes towards its original random level as the number of stimuli learned increases.

3. In such an environment, no basis for generalization exists.

4. In a "differentiated environment," where each response is associated to a distinct class of mutually correlated, or "similar" stimuli, the probability that a learned association of some specific stimulus will be correctly retained typically approaches a better-than-chance asymptote as the number of stimuli learned by the system increases. This asymptote can be made arbitrarily close to unity by increasing the number of association cells in the system.

5. In the differentiated environment, the probability that a stimulus *which has not been seen before* will be correctly recognized and associated to its appropriate class (the probability of correct generalization) approaches the same asymptote as the probability of a correct response to a previously reinforced stimulus. This asymptote will be better than chance if the inequality $P_{c12} < P_a < P_{c11}$ is met, for the stimulus classes in question.

6. The performance of the system can be improved by the use of a contour-sensitive projection area, and by the use of a binary response system, in which each response, or "bit," corresponds to some independent feature or attribute of the stimulus.

7. Trial-and-error learning is possible in bivalent reinforcement systems.

8. Temporal organizations of both stimulus patterns and responses can be learned by a system which uses only an extension of the original principles of statistical separability, without introducing any major complications in the organization of the system.

9. The memory of the perceptron is *distributed*, in the sense that any association may make use of a large proportion of the cells in the system, and the removal of a portion of the association system would not have an appreciable effect on the performance of any one discrimination or association, but would begin to show up as a general deficit in *all* learned associations.

10. Simple cognitive sets, selective recall, and spontaneous recognition of the classes present in a given environment are possible. The recognition of relationships in space and time, however, seems to represent a limit to the perceptron's ability to form cognitive abstractions.

Psychologists, and learning theorists in particular, may now ask: "What has the present theory accomplished,

beyond what has already been done in the quantitative theories of Hull, Bush and Mosteller, etc., or physiological theories such as Hebb's?" The present theory is still too primitive, of course, to be considered as a full-fledged rival of existing theories of human learning. Nonetheless, as a first approximation, its chief accomplishment might be stated as follows:

For a given mode of organization (α, β, or γ; Σ or μ; monovalent or bivalent) the fundamental phenomena of *learning, perceptual discrimination, and generalization can be predicted entirely from six basic physical parameters*, namely:

x: the number of excitatory connections per A-unit,
y: the number of inhibitory connections per A-unit,
θ: the expected threshold of an A-unit,
ω: the proportion of R-units to which an A-unit is connected,
N_A: the number of A-units in the system, and
N_R: the number of R-units in the system.

N_s (the number of sensory units) becomes important if it is very small. It is assumed that the system begins with all units in a uniform state of value; otherwise the initial value distribution would also be required. *Each of the above parameters is a clearly defined physical variable, which is measurable in its own right, independently of the behavioral and perceptual phenomena which we are trying to predict.*

As a direct consequence of its foundation on physical variables, the present system goes far beyond existing learning and behavior theories in three main points: parsimony, verifiability, and explanatory power and generality. Let us consider each of these points in turn.

1. *Parsimony.* Essentially all of the basic variables and laws used in this system are already present in the structure of physical and biological science, so that we have found it necessary to postulate only one hypothetical variable (or construct) which we have called V, the "value" of an association cell; this is a variable which must conform to certain functional characteristics which can clearly be stated, and which is assumed to have a potentially measurable physical correlate.

2. *Verifiability.* Previous quantitative learning theories, apparently without exception, have had one important characteristic in common: they have all been based on measurements of *behavior*, in specified situations, using these measurements (after theoretical manipulation) to predict *behavior* in other situations. Such a procedure, in the last analysis, amounts to a process of curve fitting and extrapolation, in the hope that the constants which describe one set of curves will hold good for other curves in other situations. While such extrapolation is not necessarily circular, in the strict sense, it shares many of the logical difficulties of circularity, particularly when used as an "explanation" of behavior. Such extrapolation is difficult to justify in a new situation, and it has been shown that if the basic constants and parameters are to be derived anew for any situation in which they break down empirically (such as change from white rats to humans), then the basic "theory" is essentially irrefutable, just as any successful curve-fitting equation is irrefutable. It has, in fact, been widely conceded by psychologists that there is little point in trying to "disprove" any of the major learning theories in use today, since by extension, or a change in parameters, they

have all proved capable of adapting to any specific empirical data. This is epitomized in the increasingly common attitude that a choice of theoretical model is mostly a matter of personal aesthetic preference or prejudice, each scientist being entitled to a favorite model of his own. In considering this approach, one is reminded of a remark attributed to Kistiakowsky, that "given seven parameters, I could fit an elephant." This is clearly *not* the case with a system in which the independent variables, or parameters, can be measured *independently* of the predicted behavior. In such a system, it is not possible to "force" a fit to empirical data, if the parameters in current use should lead to improper results. In the current theory, a failure to fit a curve in a new situation would be a clear indication that either the theory or the empirical measurements are wrong. Consequently, if such a theory *does* hold up for repeated tests, we can be considerably more confident of its validity and of its generality than in the case of a theory which must be hand-tailored to meet each situation.

3. *Explanatory power and generality.* The present theory, being derived from basic physical variables, is not specific to any one organism or learning situation. It can be generalized in principle to cover any form of behavior in any system for which the physical parameters are known. A theory of learning, constructed on these foundations, should be considerably more powerful than any which has previously been proposed. It would not only tell us what behavior might occur in any known organism, but would permit the *synthesis* of behaving systems, to meet special requirements. Other learning theories tend to become increasingly qualitative as they are generalized. Thus a set of equations describing the effects of reward on T-maze learning in a white rat reduces simply to a statement that rewarded behavior tends to occur with increasing probability, when we attempt to generalize it from any species and any situation. The theory which has been presented here loses none of its precision through generality.

The theory proposed by Donald Hebb (7) attempts to avoid these difficulties of behavior-based models by showing how psychological functioning might be derived from neurophysiological theory. In his attempt to achieve this, Hebb's philosophy of approach seems close to our own, and his work has been a source of inspiration for much of what has been proposed here. Hebb, however, has never actually achieved a model by which behavior (or any psychological data) can be *predicted* from the physiological system. His physiology is more a suggestion as to the *sort* of organic substrate which might underlie behavior, and an attempt to show the plausibility of a bridge between biophysics and psychology.

The present theory represents the first actual completion of such a bridge. Through the use of the equations in the preceding sections, it is possible to predict learning curves from neurological variables, and likewise, to predict neurological variables from learning curves. How well this bridge stands up to repeated crossings remains to be seen. In the meantime, the theory reported here clearly demonstrates the feasibility and fruitfulness of a quantitative statistical approach to the organization of cognitive systems. By the study of systems such as the perceptron, it is hoped that those fundamental laws of organization which are common to all information handling systems, ma-

chines and men included, may eventually be understood.

REFERENCES

1. ASHBY, W. R. *Design for a brain.* New York: Wiley, 1952.
2. CULBERTSON, J. T. *Consciousness and behavior.* Dubuque, Iowa: Wm. C. Brown, 1950.
3. CULBERTSON, J. T. Some uneconomical robots. In C. E. Shannon & J. McCarthy (Eds.), *Automata studies.* Princeton: Princeton Univer. Press, 1956. Pp. 99–116.
4. ECCLES, J. C. *The neurophysiological basis of mind.* Oxford: Clarendon, 1953.
5. GOLDSTEIN, K. *Human nature in the light of psychopathology.* Cambridge: Harvard Univer. Press, 1940.
6. HAYEK, F. A. *The sensory order.* Chicago: Univer. Chicago Press, 1952.
7. HEBB, D. O. *The organization of behavior.* New York: Wiley, 1949.
8. KLEENE, S. C. Representation of events in nerve nets and finite automata. In C. E. Shannon & J. McCarthy (Eds.), *Automata studies.* Princeton: Princeton Univer. Press, 1956. Pp. 3–41.
9. KÖHLER, W. Relational determination in perception. In L. A. Jeffress (Ed.), *Cerebral mechanisms in behavior.* New York: Wiley, 1951. Pp. 200–243.
10. MCCULLOCH, W. S. Why the mind is in the head. In L. A. Jeffress (Ed.), *Cerebral mechanisms in behavior.* New York: Wiley, 1951. Pp. 42–111.
11. MCCULLOCH, W. S., & PITTS, W. A logical calculus of the ideas immanent in nervous activity. *Bull. math. Biophysics,* 1943, **5**, 115–133.
12. MILNER, P. M. The cell assembly: Mark II. *Psychol. Rev.,* 1957, **64**, 242–252.
13. MINSKY, M. L. Some universal elements for finite automata. In C. E. Shannon & J. McCarthy (Eds.), *Automata studies.* Princeton: Princeton Univer. Press, 1956. Pp. 117–128.
14. RASHEVSKY, N. *Mathematical biophysics.* Chicago: Univer. Chicago Press, 1938.
15. ROSENBLATT, F. *The perceptron: A theory of statistical separability in cognitive systems.* Buffalo: Cornell Aeronautical Laboratory, Inc. Rep. No. VG-1196-G-1, 1958.
16. UTTLEY, A. M. Conditional probability machines and conditioned reflexes. In C. E. Shannon & J. McCarthy (Eds.), *Automata studies.* Princeton: Princeton Univer. Press, 1956. Pp. 253–275.
17. VON NEUMANN, J. The general and logical theory of automata. In L. A. Jeffress (Ed.), *Cerebral mechanisms in behavior.* New York: Wiley, 1951. Pp. 1–41.
18. VON NEUMANN, J. Probabilistic logics and the synthesis of reliable organisms from unreliable components. In C. E. Shannon & J. McCarthy (Eds.), *Automata studies.* Princeton: Princeton Univer. Press, 1956. Pp. 43–98.

(Received April 23, 1958)

ZEITSCHRIFT FÜR EXPERIMENTELLE UND ANGEWANDTE PSYCHOLOGIE

Organ der Deutschen Gesellschaft für Psychologie

Herausgeber für Deutschland

PROF. DR. PH. LERSCH, München; PROF. DR. F. SANDER, Bonn

Herausgeber für Österreich	Herausgeber für die Schweiz	Redaktion
PROF. DR. H. ROHRACHER, Wien	PROF. DR. R. MEILI, Bern	DR. C. J. HOGREFE, Göttingen

Band V/1

GOTTFRIED EWALD, **Psychologie, Psychotherapie und Psychiatrie**

ROLF AHRENS, **Zur Bedeutung der Psychologie für das Aphasieproblem**

ERICH MITTENECKER, **Die Analyse "zufälliger" Reaktionsfolgen**

ANNELIESE KRANTZ-GROSS und HANS-JOACHIM HAASE, **Psychomotorik des Griffdrucks bei endogenen Depressionen**

GUSTAV A. LIENERT, **Ein Formlegetest als Prüfmittel der praktischen Intelligenz**

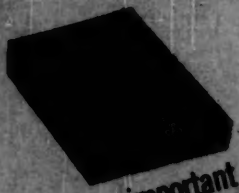
EBERHARD ULICH, **Neue Erfahrungen mit dem Pauli-Test**

ANNE-MARIE TAUSCH, **Empirische Untersuchungen über das Verhalten von Lehrern gegenüber Kindern in erziehungsschwierigen Situationen**

All articles are provided with summaries in English and French.

The journal appears quarterly and contains 160 pages per number.
Subscription is DM 64.— per volume.

VERLAG FÜR PSYCHOLOGIE • DR. C. J. HOGREFE • GÖTTINGEN
(Brentanoweg 10, Germany)



Two new important evergreen Psychology Books

In fine soft-cover editions at $1.95 and up

THE SEARCH WITHIN, by Theodor Reik. The famous psychoanalyst focuses upon himself with unsparing candor in this brilliant distillation of this thoughts and experiences. $2.95

WHO ARE THE GUILTY? by David Abrahamsen, M.D. The burning question of juvenile delinquency receives its most penetrating answer to date as the famous psychiatrist details his clear-cut prescription for preventative action. $1.95

Masochism in Modern Man by *Theodor Reik.* $1.95

A Study of Interpersonal Relations. Edited by *Patrick Mullahy.* $3.45

Psychoanalysis: Evolution & Development by *Clara Thompson and Patrick Mullahy.* $1.75

Black Anger. A unique psychoanalytic biography of a native African medicine man, by *Wulf Sachs.* $1.75

Education and Human Relations by *Ashley Montagu.* $1.45

The Forgotten Language. An Introduction to the Understanding of Dreams, Fairy-tales and Myths, by *Erich Fromm.* $1.75

Rebel Without a Cause. The hypnoanalysis of a criminal psychopath, by *Robert M. Lindner.* $1.75

The Biosocial Nature of Man by *Ashley Montagu.* $1.25

Democracy and Dictatorship. A study of the conditions that produce each, by *Zevedei Barbu.* $1.45

Listening with the Third Ear by *Theodor Reik.* $1.95

Jung's Psychology and its Social Meaning by *Ira Progoff.* $1.75

Oedipus: Myth and Complex by *Patrick Mullahy.* $1.95

Specialized Techniques in Psychotherapy. Edited by *Gustav Bychowski, M.D. and J. Louise Despert, M.D.* $1.95

The Marquis de Sade. An essay by *Simone de Beauvoir* with selections from De Sade's writings. $1.75

At all bookstores • *Send for free descriptive catalog* · GROVE PRESS 795 Broadway, N. Y. 3

THE BRITISH JOURNAL OF PSYCHOLOGY

Edited by BORIS SEMEONOFF

Vol. 49, Part 3. August 1958. 20s. net.

Obituary Notice: Ernest Jones.

JAMES J. GIBSON. Visually controlled locomotion and visual orientation in animals.

S. A. BARNETT. Experiments on 'neophobia' in wild and laboratory rats.

R. L. REID. The role of the reinforcer as a stimulus.

N. H. MACKWORTH and J. F. MACKWORTH. Visual search for successive decisions.

S. FRIEDMANN. The role of attitudes in comprehension.

R. C. POULTON. Time for reading and memory.

H. J. EYSENCK and P. SLATER. Effects of practice and rest on fluctuations in the Muller-Lyer illusion.

PUBLICATIONS RECENTLY RECEIVED.

OTHER PUBLICATIONS RECEIVED.

The subscription price per volume, payable in advance, is 60s. net (post free).

Subscriptions may be sent to any bookseller or to the

CAMBRIDGE UNIVERSITY PRESS

Bentley House, Euston Road, London, N.W. 1.